T. 1588.

D.2. Misc., 132.

AERONAUTICS.

REPORT

OF THE

AERONAUTICAL RESEARCH COMMITTEE

FOR THE YEAR 1920-21.

Presented to Parliament by Command of His Majesty.

LONDON:
PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE.

To be purchased through any Bookseller or directly from
H.M. STATIONERY OFFICE at the following addresses:
IMPERIAL HOUSE, KINGSWAY, LONDON, W.C. 2;
28, ABINGDON STREET, LONDON, S.W. 1;
37, PETER STREET, MANCHESTER;
1, ST. ANDREW'S CRESCENT, CARDIFF;
23, FORTH STREET, EDINBURGH;
or from E. PONSONBY, LTD., 116, GRAFTON STREET, DUBLIN.

1921.

[Cmd. 1458.] *Price 6d. Net.*

MEMBERS OF THE COMMITTEE, MARCH, 1921.

Professor Sir RICHARD GLAZEBROOK, K.C.B., F.R.S. (Chairman).

Sir JOSEPH E. PETAVEL, K.B.E., D.Sc., F.R.S. (Vice-Chairman).

Professor L. BAIRSTOW, C.B.E., F.R.S.

Wing-Commander W. D. BEATTY, C.B.E., A.F.C.

Air Commodore H. R. M. BROOKE-POPHAM, C.B., C.M.G.

Wing-Commander T. R. CAVE-BROWN-CAVE, C.B.E.

Professor J. D. CORMACK, C.M.G., C.B.E., D.Sc., M.Inst.C.E.

Professor W. E. DALBY, M.A., B.Sc., F.R.S.

Lieut.-Colonel E. GOLD, D.S.O., F.R.S.

Professor B. M. JONES, M.A.

Professor HORACE LAMB, M.A., D.Sc., F.R.S.

Mr. A. OGILVIE, C.B.E., M.I.Mech.E.‡

Mr. J. D. SIDDELEY, C.B.E.*

Mr. H. WHITE SMITH, C.B.E.*

Mr. G. I. TAYLOR, M.A., F.R.S.

Mr. H. T. TIZARD, M.A.

Secretary, Mr. J. L. Nayler,
National Physical Laboratory,
Teddington.

Assistant Secretary, Mr. J. G. Gibson,†
Mr. H. B. Irving.

---

* Representing the Society of British Aircraft Constructors.

† Mr. Irving replaced Mr. Gibson in December, 1920, on his appointment to other work.

‡ Representing the Royal Aeronautical Society.

Report for the Year 1920-21.

May, 1921.

To CAPTAIN THE RIGHT HONOURABLE F. E. GUEST, C.B.E., D.S.O., M.P., SECRETARY OF STATE FOR AIR.

SIR,

The Aeronautical Research Committee begs to submit its report for the year 1920–21.

In the month of March, 1920, the Air Ministry took the necessary steps to reconstitute the late Advisory Committee for Aeronautics, and nominated the members of the present Committee.

The Air Council, in their letter of appointment to individual members, stated they wished the Aeronautical Research Committee to assist them in carrying out their responsibility in regard to research in aeronautics, and to devote itself generally to the advance of aeronautical science. The terms of reference of the Committee include the following duties :—

(1) To advise on scientific and technical problems relating to the construction and navigation of aircraft ;

(2) to undertake or supervise such research or experimental work as is proposed to the Committee by the Air Ministry, and to initiate any research work which the Committee considers to be advisable ; to carry out such work itself or to recommend by whom the work should be carried out ;

(3) to take over complete responsibility for the Air Inventions Committee and for the Accidents Committee ;

(4) to promote education in aeronautics by co-operating with the Governors of the Imperial College ;

(5) to assist the aeronautical industry of the country by scientific advice and research, and to co-operate with any Research Association that may be established ;

(6) to prepare for the approval of the Air Council a scheme of work and estimate of expenditure for the year, and to administer the funds placed at its disposal by the Air Council ;

(7) to make reports from time to time to the Air Council.

(B5665) Wt. 9—203/127. 875 & 90. 8/21. **Gp. 32.**

The Council has appointed in all some sixteen members constituted as follows :—

(*a*) Four Air Ministry representatives. (Official.)
(*b*) Two representatives of the Aircraft Industry. (Independent.)
(*c*) One representative of the Royal Aeronautical Society. (Independent.)
(*d*) Two representatives of the Imperial College of Science of whom one will be the Chairman of the Committee, Professor Sir R. T. Glazebrook, K.C.B., F.R.S.
(*e*) Two representatives of the Department of Scientific and Industrial Research. (Official.)
(*f*) Five representatives of Science. (Independent.)

The Committee met for the first time on Tuesday, 11th May, and made the necessary arrangements for carrying out the wishes of the Air Council. At that meeting it was explained that the six official members should serve on the Committee while holding their appointments, and the nine non-official independent members were placed on a rota of service for periods up to three years, the first three being appointed only for one year, the second for two years, and the third for three years ; all non-official members are eligible for re-appointment on the completion of their term of service.

The work of the Committee has been largely carried on through Sub-Committees* which include the following :—

(1) Aerodynamics Sub-Committee.
(2) Engine Sub-Committee.
(3) Materials and Chemistry Sub-Committee.
(4) Meteorology, Navigation and Atmospheric Electricity Sub-Committee.
(5) Accidents Investigation Sub-Committee.
(6) Fire Prevention Sub-Committee.
(7) Load Factors Sub-Committee.
(8) Air Inventions Sub-Committee.

---

* At the commencement of the year the membership of these Sub-Committees was composed as follows :—

Air Inventions Sub-Committee.—Sir R. T. Glazebrook, K.C.B., F.R.S. (Chairman) ; Professor L. Bairstow, C.B.E., F.R.S. ; Wing Commander T. R. Cave-Browne-Cave, C.B.E. ; Professor B. M. Jones, M.A. ; Sir J. E. Petavel, K.B.E., F.R.S. ; Mr. G. I. Taylor, M.A., F.R.S. ; Major H. E. Wimperis, O.B.E., of the Air Ministry Laboratory.

Aerodynamics Sub-Committee.—Sir J. E. Petavel, K.B.E., F.R.S. (Chairman) ; Professor L. Bairstow, C.B.E., F.R.S. ; Professor B. M. Jones, M.A. ; Professor H. Lamb, M.A., D.Sc., F.R.S. ; Mr. Alec Ogilvie, C.B.E., M.I.Mech.E. ; Mr. G. I. Taylor, M.A., F.R.S. ; Mr. H. White Smith, C.B.E. ; Wing Commander T. R. Cave-Browne-Cave, C.B.E. ; J. D. Coales, D.Sc., and Mr. R. J. Goodman Crouch, of the Air Ministry ; Mr. C. I. Campbell, of the Royal Airship Works ; Mr. R. V. Southwell, M.A., and Mr. E. F. Relf, A.R.C.Sc., of the National Physical Laboratory ;

These Sub-Committees have dealt with the detailed consideration of almost all the technical questions which have arisen during the past year, and have reported monthly to the Main Committee.

The Aerodynamics Sub-Committee have discussed all matters relating to full-scale and model work on aircraft, and the application of the results obtained by experiments on models to the full-scale craft. They have included in their purview aeroplanes, airships, flying boats and questions connected with kite balloons and parachutes; also matters relating to the design of aeroplanes as regards structural strength. For the consideration of special papers, four panels, on airships, control and stability, airscrews and design, have been appointed.

The Engine Sub-Committee have carried on the work previously dealt with by the Engine Committee of the Advisory Committee for Aeronautics, and have considered questions relating to aircraft engines, from the point of view of the power plant, the ignition, the installation and the fuels employed.

Squadron Leader R. M. Hill and Mr. R. McK. Wood, of the Royal Aircraft Establishment; Major F. H. Bramwell; Captain W. S. Farren, M.B.E.; Lieut.-Colonel Mervyn O'Gorman, C.B.; Squadron Leader A. J. Miley, O.B.E., of the Air Ministry (*vice* Major Linton-Hope, M.I.N.A., F.R.Ae.S., deceased); Captain F. S. Barnwell and Mr. J. D. North, representing the Society of British Aircraft Constructors; Dr. H. C. Watts, A.M.I.C.E.; with the Chairman of the Aeronautical Research Committee (*ex officio*).

Engine Sub-Committee.—Professor W. E. Dalby, M.A., B.Sc., F.R.S. (Chairman); Mr. Alec Ogilvie, C.B.E., M.I.Mech.E.; Sir J. E. Petavel, K.B.E., F.R.S.; Mr. J. D. Siddeley, C.B.E.; Mr. H. T. Tizard, M.A.; Professor H. L. Callendar, F.R.S.; Professor A. H. Gibson, D.Sc.; Lieut.-Colonel Mervyn O'Gorman, C.B.; Mr. H. R. Ricardo; Wing-Commander T. R. Cave-Browne-Cave, C.B.E.; J. D. Coales, D.Sc., Squadron Leader B. C. Carter, and Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., of the Air Ministry; Squadron Leader R. G. Parry, of the Royal Airship Works, Cardington; Major H. E. Wimperis, O.B.E., of the Air Ministry Laboratory; Dr. T. E. Stanton, of the National Physical Laboratory; Squadron Leader G. H. Norman, of the Royal Aircraft Establishment; Brigadier-General R. K. Bagnall-Wild, C.B.E., C.M.G., of the Aeronautical Inspection Directorate; Mr. T. B. Barrington and Mr. A. J. Rowledge, representing the Society of British Aircraft Constructors; with the Chairman of the Aeronautical Research Committee (*ex officio*).

Materials and Chemistry Sub-Committee.—Professor C. F. Jenkin, C.B.E., M.A., M.Inst.C.E. (Chairman); Professor L. Bairstow, C.B.E., F.R.S.; Professor W. E. Dalby, M.A., B.Sc., F.R.S.; Sir J. E. Petavel, K.B.E., F.R.S.; Mr. H. White Smith, C.B.E.; Mr. J. D. Siddeley, C.B.E.; Mr. G. I. Taylor, M.A., F.R.S.; Mr. H. T. Tizard, M.A.; Dr. L. Aitchison; Professor F. C. Lea; Dr. A. J. Sutton Pippard, M.B.E., A.M.I.C.E.; Sir Robert Robertson, F.R.S.; Mr. J. W. W. Dyer and Mr. S. Payne, of the Royal Airship Works, Cardington; Mr. A. Young, of the Air Ministry; Dr. G. Barr, B.A., Dr. G. W. C. Kaye, B.A., Dr. W. Rosenhain, F.R.S., Mr. R. V. Southwell, M.A., and Dr. T. E. Stanton, F.R.S., of the National Physical Laboratory; Mr. W. D. Douglas and Dr. J. E. Ramsbottom, of the Royal Aircraft Establishment; Brigadier-General R. K. Bagnall-Wild, C.B.E., C.M.G., of the Aeronautical Inspection Directorate; Mr. J. D. North and Mr. A. J. Rowledge, representing the Society of British Aircraft Constructors; with the Chairman of the Aeronautical Research Committee (*ex officio*).

One of the main questions with which they have been concerned is that of reliability, and a small panel appointed for this purpose has discussed from time to time detailed questions.

Materials of construction are discussed by another Sub-Committee, who include in their terms of reference the questions relating to mechanical tests on all types of materials (metal, timber, fabrics, &c.) and have, in addition, dealt with several chemical questions.

The Meteorology Sub-Committee of the Advisory Committee for Aeronautics was reconstituted to carry on the work of that Committee and of the Special Committee for the Electrification of Balloons. The Sub-Committee has in addition dealt with several important questions relating to the navigation of aircraft.

The Accidents Sub-Committee have continued the work of the previous Committee, carrying out at the request of the Ministry enquiries into the specific causes and prevention of such accidents

---

Meteorology Sub-Committee.—Sir Napier Shaw, F.R.S. (Chairman); Professor B. M. Jones, M.A.; Professor H. Lamb, M.A., D.Sc., F.R.S.; Mr. G. I. Taylor, M.A., F.R.S.; Squadron Leader G. G. H. Cooke, D.S.C., A.F.C.; Mr. G. M. B. Dobson; Mr. W. H. Dines, F.R.S.; Professor F. A. Lindemann; Mr. F. E. Smith, O.B.E., F.R.S.; Mr. C. T. R. Wilson, F.R.S.; Wing Commander T. R. Cave-Browne-Cave, C.B.E.; Lieut.-Colonel E. Gold, D.S.O., F.R.S., Dr. G. C. Simpson, Colonel L. F. Blandy, D.S.O., Flight-Lieut. R. S. Capon, of the Air Ministry; Major H. E. Wimperis, O.B.E., of the Air Ministry Laboratory; Dr. T. E. Stanton, F.R.S., of the National Physical Laboratory; Mr. G. L. Smith, of the Royal Aircraft Establishment; with the Chairman of the Aeronautical Research Committee (*ex officio*).

Accidents Investigation Sub-Committee.—Lieut.-Colonel Mervyn O'Gorman, C.B. (Chairman); Professor L. Bairstow, C.B.E., F.R.S.; Sir J. E. Petavel, K.B.E., F.R.S.; Mr. G. B. Cockburn, O.B.E.; Dr. A. J. Sutton Pippard, M.B.E., A.M.I.C.E.; Lieut.-Colonel E. Gold, D.S.O., F.R.S., Mr. M. A. Doyle and Squadron Leader Pritchard, of the Air Ministry; Squadron Leader R. M. Hill, of the Royal Aircraft Establishment; with the Chairman of the Aeronautical Research Committee (*ex officio*).

Fire Prevention Sub-Committee.—Lieut.-Colonel Mervyn O'Gorman, C.B. (Chairman); Sir J. E. Petavel, K.B.E., F.R.S.; Mr. G. B. Cockburn, O.B.E.; Wing Commander T. R. Cave-Browne-Cave, C.B.E., and Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., of the Air Ministry; Squadron Leader G. H. Norman and Dr. J. E. Ramsbottom, of the Royal Aircraft Establishment; Mr. F. M. Green and Mr. R. K. Pierson, representing the Society of British Aircraft Constructors; with the Chairman of the Aeronautical Research Committee (*ex officio*).

Load Factor Sub-Committee.—Sir R. T. Glazebrook, K.C.B., F.R.S. (Chairman); Professor C. F. Jenkin, C.B.E., M.A., M.Inst.C.E., Sir J. E. Petavel, K.B.E., F.R.S., Dr. T. E. Stanton, F.R.S., and Mr. R. V. Southwell, M.A., representing the Aeronautical Research Committee; Lieut.-Colonel Mervyn O'Gorman, C.B., and Capt. G. de Havilland, O.B.E., A.F.C., representing the Royal Aeronautical Society; Mr. F. Handley Page, Captain F. S. Barnwell, Mr. J. D. North, and Mr. O. Short, representing the Society of British Aircraft Constructors; Wing Commander W. D. Beatty, C.B.E., and Mr. R. J. Goodman Crouch, representing the Air Ministry.

to aircraft as appeared to require special technical investigation. In particular, enquiry has been made into the cases of accidents to the F type flying boats, the Tarrant Tabor and the Airship R.36.

The causes and prevention of fire on aeroplanes both in the air and on crash has occupied the attention of the Fire Prevention Sub-Committee, who will report shortly on the many possible causes of fire on crash, their probable frequency and the means by which the fire can, in certain cases, be prevented. Their preliminary recommendations have been adopted, and action has been taken in accordance with them.

The Load Factors Sub-Committee has only recently been reconvened to deal with various questions brought to the attention of the Air Council by the Society of British Aircraft Constructors.

The Air Inventions Sub-Committee have not met during the past year as matters which necessitated reference to this Sub-Committee for a decision on technical detail have not come before the Air Inventions Department.

Publication of reports presented to the Main Committee and to its Sub-Committees.—The Committee have each month approved for issue a selection of the reports which have been discussed at their meeting, following in this respect the practice of the Advisory Committee for Aeronautics. Arrangements have been made with H.M. Stationery Office for the publication and issue of all approved matter, and the office issue each month a statement of the Reports and Memoranda placed on sale during this period. There is some small risk in this rapid publication, for it is inevitable that it should sometimes be necessary to revise the views reached and even the experimental results obtained in the light of later work. Every effort is, however, made to secure the necessary accuracy in all technical information that is communicated to the public, and the Committee believe early publication to be of real value to the industry.

Liaison work.—The Committee are in correspondence with the various aeronautical laboratories in allied countries, and have instituted a series of preliminary tests on a number of models which are to be tested in these laboratories in order that strict comparison may be made between the experimental results at the various institutions. In addition, close touch is maintained with the Associate Air Research Committee in Canada. To the latter a copy of the Scheme of Research for the year 1920–21 has been forwarded, and information as to Canadian researches has been supplied in return. Mention should also be made of the exchange of information with the American National Advisory Committee for Aeronautics through Mr. William Knight, their technical assistant, stationed at Paris. The work dealing with the above matters has been considerable, but it has been found

possible to cope with it and to keep in close touch with all the aeronautical bodies concerned.

Equipment for experimental work at the N.P.L. and Royal Aircraft Establishment.—The facilities for carrying out experimental work at these two establishments have been considerably increased during the last few years. Both institutions have completed a number of investigations for the Engine, Materials and Fire Prevention Sub-Committees. The N.P.L. is equipped for experiments on models and for such other work as can suitably be carried out in a central research laboratory.

This equipment at the N.P.L. comprises in the Aerodynamics Department a duplex channel measuring 14 ft. by 7 ft., three 7 ft. channels, two 4 ft. channels and one 3 ft. channel. Excepting the duplex, which has only just been completed, all the channels have been in full working order during the past three years. The duplex channel at the time of writing has recently been calibrated and found very satisfactory as regards uniformity of flow and steadiness of air current. In this channel it is hoped to make experiments in directions in which the scale effect between model aeroplane work and full-scale is more pronounced. Amongst such items is included the determination of the centre of pressure on wing sections at low lift coefficients. In the Engineering and Metallurgy Departments facilities exist for the various researches on aeronautical matters detailed elsewhere in this report, and in the William Froude National Tank tests are made on various forms of hulls for flying boats.

The R.A.E. has devoted attention to full-scale work on aeroplanes, engines, propellers, &c., and also to researches on instruments, but in addition the staff has carried out a large number of tests on model aeroplanes and their parts. The equipment for these purposes includes two 7 ft. wind channels and one 4 ft., a complete installation capable of making tests on aircraft engines of all sizes up to 1,200 h.p.; a whirling arm for full-scale propeller tests; foundry and factory facilities for the production of experimental aeroplanes and engines, and well-equipped chemical, physical and engineering laboratories for the study of special problems. In addition plant for tests under high altitude conditions for engines up to 1,000 h.p. is being provided.

Aerodynamics.—The work on special problems of aerodynamics has been under the direction of the Aerodynamics Sub-Committee, who have arranged a series of fundamental researches involving lengthy investigations. Among these should be mentioned an investigation now in hand at the N.P.L. on the stability of certain complete rigged models. A preliminary report on the longitudinal stability of these machines has been issued, and the characteristics of their lateral stability are now being carefully examined. The programme was initiated at the commencement as a result of an arrangement that a complete

model of any new type of aeroplane should be submitted to the N.P.L. for a thorough investigation of its stability, and the Committee are of opinion that, by carrying to a conclusion experiments on this subject, it will shortly be possible to define the conditions requisite to secure stability in any new type of machine. During the summer of 1921 it is hoped to devote two channels entirely to stability experiments.

Up to the present the Accidents Investigation Sub-Committee have not been in a position in the case of certain accidents to distinguish between the defective stability of the aircraft and certain other causes of trouble. The above experiments on the series of complete models should elucidate many points that have arisen in this connection, and, in particular, a few discrepancies now existing between stability characteristics predicted from the model and their realisation on the larger types of aeroplane should be cleared up.

A research on ailerons commenced in the previous year has been continued, and a number of reports relating to model experiments on different types of ailerons have been issued. The experiments consisted in the measurement of rolling and hinge moments for various settings of the ailerons, and in one case pressure plotting measurements were completed over the wing with the aileron set at zero incidence relative to the wing. From the results of the model tests, coupled with flying experience, it is now established that the horn type of balance possesses some undesirable features which may become prominent or even dangerous in large machines. A more satisfactory type is that in which balance of the aileron is obtained by placing the hinge some distance behind the leading edge.

Mention should here be made of a large amount of full-scale work carried out at the R.A.E. for direct comparison between model work and the full scale trial. In many cases the comparative model work has been carried out at the R.A.E. in their own wind channels. Two reports have been issued giving the existing scale effects for the R.A.F. 15 and 18 wing sections; these are of the same order of magnitude as those given in the report of the Scale Effect Sub-Committee in 1916 on the B.E. aeroplane.

Aeroplane Carrier Ships.—At the request of the Director of Naval Construction, further experiments have been made on aeroplane carrier ships to investigate the flow of air over the deck. During the summer, full-scale trials on H.M.S. Eagle were made, and these have now been analysed at the N.P.L. The analysis shows that the difference as regards velocity and direction of wind on the model and the actual ship are within the error of experiment, so that model work promises well as an aid to future design.

Airscrews.—The Aerodynamics Sub-Committee appointed a panel to discuss what were the most urgent requirements for airscrew design. Following on their recommendations the N.P.L. have commenced a series of tests on a family of airscrews of various pitch diameter ratios, the airscrew being mounted in the wind channel in front of, or behind, a standard stream-line body. In the experiments now in hand, this body has a diameter of about one-third that of the airscrew, but the experiments are to be extended so as to include both the case when the aeroplane body shall have a diameter approximating to that of the airscrew itself, and the case when the airscrew is placed eccentrically to correspond to the conditions obtaining in a flying boat. The former will prepare the way for the installation of larger bodies on aeroplanes whenever it becomes possible to house in the body more portions of the structure than can be made in the aeroplane of to-day.

A most important research having a bearing on general airscrew theory is an investigation which has just been completed on the distribution of pressure over the entire surface of an airscrew blade. The model work has been carried out in a 7 ft. channel at the N.P.L., and an analysis of the experimental data has been made with a view to the advancement of airscrew theory. It follows from these experiments that the theoretical prediction of the thrust of an airscrew is accurate to within 2 per cent., but, if frictional effects be neglected, there is a difference of 15 per cent. between the observed and calculated values of the torque.

Various other problems have been attacked, including (1) the effect of the proximity of a plane surface on the performance of an airscrew—this has an application to the fitting of airscrews near the hull of an airship, and (2) the comparative performance of various airscrews for the S.E.5A aeroplane with a Wolseley Viper engine in which the comparison has been made both in the full-scale and model experiments. These last show that small airscrews running at high speeds can in certain cases be made as efficient as others of larger diameter running at slower speeds.

Mention may here be made of an investigation of the sounds given out by aeroplanes. It was considered probable from the experimental results that the sound first heard from a distant aeroplane comes partly from the engine and partly from the airscrew ; for the noise from the former, as heard from close quarters, could be greatly reduced by the use of exhaust silencers, but no corresponding reduction was observed in the maximum range of audibility. This result has an important bearing on the possibility of locating hostile aircraft by sound.

Seaplanes.—Seaplane researches have been continued at the N.P.L. by the staff of the William Froude National Tank, who have investigated, on a model, the effect of loading up a float of given beam, and have measured the pressure on the full-scale hull of

a flying boat when landing on the water. In this investigation, the pressure on the different portions of the hull was measured under a variety of flying conditions on an F type boat, and these are to be repeated in the near future on the P type boat which has a less rigid form of construction.

Airships.—The Committee have learnt with great regret of the decision to stop or greatly to reduce all work connected with airships, and have addressed a letter to the Ministry pointing out the importance of full scale research, not only for airship progress, but as an essential part of general aerodynamic theory upon which the design of all types of aircraft depends.

Considerable progress has been made with the collection of aerodynamic data connected with airships. Full scale trials have been made in R.26, R.29 and R.32. In these trials, deceleration tests to determine the ship's resistance were made and the turning circles at various speeds were determined.

Some experiments on the stability of R.29 are of great interest. The turning circle and other characteristics of the ship's performance were observed with the ship in its original condition and with successive portions of the fabric removed from the top stabilising fin. When the whole of this fabric was removed the airship was definitely unstable. Corresponding wind tunnel tests on models have been made in order to connect the model with the full scale work. The agreement of the observations made on the full scale with those which might have been predicted from the model tests is very good.

An accurate knowledge of the pressure distribution over the fins of an airship is specially important by reason of the severe restrictions on the weight of the structure of the planes imposed by the comparatively small buoyancy of that part of the ship. Some failures have actually occurred in flight, and the problem is therefore under very careful investigation. In addition to model work pressure plotting records on the fins of R.32 have been made, and similar observations will shortly be made on R.38.

The distribution of pressure over the hull is also important as affecting the necessary structural strength and the arrangement of hatches for the ventilation and cooling of the interior of the hull.

The full scale work that has been possible up to the present forms, when compared with the corresponding model tests, a very valuable contribution to the general theory relating to model and full scale work on all aircraft. Its importance is therefore not limited merely to the application to airship design.

Stability and Control.—Mention has already been made of a number of experiments contemplated or in hand on the stability of aeroplanes. In addition the problem of control, especially at low speeds, has been receiving earnest consideration. The present

day aeroplanes cannot be landed at speeds slightly below that of stalling as the lateral control becomes inoperative. Experiments have been initiated on various methods of overcoming this difficulty; one of the most promising suggestions is the use of interplane ailerons in place of those normally fixed on the wings. The amount of yawing moment caused by this type of aileron is relatively small, but unfortunately the performance of the aeroplane will probably be adversely affected to a considerable degree in consequence of their extra resistance. Full scale experiments are to be undertaken and they should show what are exactly the advantages to be gained by improvement in the lateral control at low speeds. Should these advantages prove to be large it is possible that they may outweigh any reduction in performance which is entailed. The study of this problem is most important for safety in flying. Not only must an engine of an aeroplane be reliable in flight but the machine must also be able to land safely in the restricted area of the aerodrome. If greater control can be obtained at low speeds, then it will be possible to increase the maximum speed of the aeroplane while retaining the same virtual stalling speed.

As an alternative the employment of high lift wings, such as the Handley Page or of a wing of variable camber, has been proposed but here also the same problem is important, namely, how to improve the inadequate control when the aeroplane is flying at speeds approaching that of stalling.

Engines.—The most important question in connection with aeroplane engines is that of reliability. To this special attention has been paid, and the Air Ministry are making an analysis of engine failures covering a long period of service. In the main, failure of the power plant occurs not in the engine itself but in one of the many auxiliaries. The sparking plug has also been a cause of trouble.

The development of an engine with high compression ratio is under consideration and various devices to increase its efficiency have been discussed. It is hoped to proceed with research on this problem by introducing modifications into existing designs of engine.

Fuels of a high flashpoint have been examined. Flight experiments on these fuels are in progress at the R.A.E., and it has been found that although some difficulties are experienced in starting engines with these fuels, they can be overcome. The use of a high flash-point fuel involves a slight increase in consumption and a decrease in the power developed.

One of the difficulties associated with the use of heavier fuels is detonation, and a lengthy research on the whole question on lines suggested by Sir Dugald Clerk is in progress at the N.P.L. The early difficulties arising in the commencement of a research of this nature have now been surmounted.

In connection with these questions reference should be made to the paper by Mr. Ricardo on "Some Possible Lines of Development in Aircraft Engines," read before the Royal Aeronautical Society, which has been the subject of careful discussion by the Committee. It is hoped to carry out further researches of the kind described in the paper. Matters relating to ignition, particularly as regards the fireproofness of magnetos, have received attention, and continuous research on this subject has been carried on at the R.A.E., who have at the same time kept in touch with the requirements of the industry.

The internal combustion turbine has been discussed in considerable detail, and a report summarising the present position has been issued. In this report attention is drawn to the low efficiency attainable at the present time with this type of prime mover.

Fire Prevention on Aircraft.—A preliminary report on fire prevention in aircraft and an account of various experiments bearing on such questions was issued early last year. Since that date the Fire Prevention Sub-Committee have confined their attention principally to the causes of fire in crash, as the frequency of the occurrence of fires in the air is much less. The latter are possibly in the main caused by backfiring, by the collection of petrol or vapour which may have access to leaks from inlet or exhaust pipes, or to occasional sparks. Attention is directed to the joints of the inlet and exhaust pipes which should be constructed and jointed so as to withstand a pressure of 20 lbs. /sq. in., and be located to discharge in a safe place.

The possible causes of ignition of an aeroplane on crash are, on the other hand, very numerous, and mention is made of these in the supplement to this report. They can be divided roughly into those from the hot parts of the engine, from the ignition system and from incidental causes. The Sub-Committee propose to issue a report dealing in detail with the cause and prevention of fire when an aeroplane crashes.

Meteorology.—As affecting aviation fog and the possibilities of its dispersion, is an important question, and on this subject the Meteorology Sub-Committee are shortly issuing a report. Three methods for dispersing fog have been considered, viz., the mechanical, thermal and electrical. Each is suitable for clearing small volumes of air of the small fog or mist particles contained in it, but their application to large volumes such as that of the slowly drifting air over an aerodrome is not a feasible proposition. Other means will have to be found to assist aviation in the difficulties of navigation in fog, and amongst these may be mentioned the choice of suitable aerodromes normally free from fog, or of alternate sites, one of which may be expected to be free from fog on any given day, and the development of mechanical means for the safe landing of an aeroplane in the fog. In connection with this last the Air Ministry are experimenting with

kite balloons to be flown at such a height that they mark the position from which a given type of aeroplane can be glided safely into an aerodrome. Other methods involving the mechanical movement of the controls independent of the pilot's action are also under consideration.

In connection with navigation, careful attention has been paid to recording and other instruments for use during flight. The accuracy of altimeters can be considerably improved, and a recommendation to this effect has been made to the Air Ministry. Various methods of calibration of altimeters have been considered and, for ease of co-operation with allied powers, it has been arranged by the Air Ministry to adopt Toussaint's formula to express the relation between height temperature and pressure. Other formulæ give greater accuracy for height determinations and the comparison of height records, but the differences between the readings of these and on the Toussaint basis are small.

The R.A.E. and other types of sextant have been tried out in various navigation flights, including one of 1,000 miles on a Handley Page aeroplane and another on a rigid airship. The determination of position by dead reckoning on the latter is equally as effective as that obtainable at sea, but on the aeroplane the accuracy is much less, being at present not greater than 10 per cent. for flights of two or three hundred miles. The use of flares over the sea or inland water was found of great value, and gave results of the same order of accuracy as sights taken from an easily determinate point on land.

To increase our knowledge of the structure of the atmosphere at different altitudes a scheme for using unmanned kite balloons carrying recording instruments has been proposed. It is hoped that the scheme will be shortly developed by the Air Ministry.

General questions bearing on the theory of the formation of cyclones have also been carefully discussed.

Materials of Construction.—An extensive programme to investigate the properties of materials used in aeronautical constructional work has been commenced under the direction of the Materials Sub-Committee. This includes the continuation of the study of light alloys, an enquiry into the fatigue properties of metals and a number of experiments on fabrics and dopes at the N.P.L. and the R.A.E. Investigations of the strength of aeroplane structures have continued at the R.A.E., where the staff has also paid attention to certain metallurgical and chemical problems. In connection with work at Universities and other technical institutions a special programme has been drafted for which definite funds have been allocated by the Department of Scientific and Industrial Research. This programme includes, in co-operation with the N.P.L., a continuation of the work carried

out under the direction of the late Light Alloys Sub-Committee and experiments on certain definite properties of a number of metals; in particular further information is needed to assess the value of a new theory on the strength of materials as developed by Mr. A. A. Griffiths, of the R.A.E., in a recent paper to the Royal Society.

A number of matters have been reported upon during the past year. Static tensile tests have been made on duralumin and suggest that the elastic limit of this material is not high, Experiment has shown that very soft rivets composed of nearly pure aluminium are not necessary for airship work since perfectly satisfactory joints can be made using either cold drawn and annealed wire of 3/20 alloy or duralumin wire. Details and working instructions for the preparations of cuprammonium solutions of cellulose and the determinations of the viscosity of such solutions are reported. A general comparison of various metals for aeroplane construction has been made showing that for flanges of members subject to bending and for beams of a given flexibility there is little to choose between 45-ton steel and duralumin but that for strut members, weight for weight, duralumin is as strong as steel, having a modulus of elasticity of 13,200 tons/sq. in. Thus for small aeroplanes duralumin is preferable, but for large machines steel should prove the better material.

Signed on behalf of the Committee,

R. T. GLAZEBROOK,

Chairman.

SUPPLEMENT TO THE REPORT FOR THE YEAR 1920—1921.

CONTENTS.

	Page
Aerodynamics	17
Engines	26
Meteorology	32
Fire Prevention	39
Materials and Chemistry	46
Fabrics and Dopes	50
Accidents	51

SUPPLEMENT TO THE REPORT FOR THE YEAR 1920—1921.

In this Supplement specific mention is made of many of the more important problems and matters dealt with by the various Sub-Committees. The matters are arranged as far as possible under appropriate sub-headings.

Aerodynamics.

Aerodynamics Sub-Committee.—This Sub-Committee has met many times during the past year, and has considered a large number of papers submitted to them by the National Physical Laboratory, the Royal Aircraft Establishment, and the Air Ministry. It has dealt with questions on aeroplanes, airships and seaplanes, from the point of view of both full-scale tests and model experiments. For the discussion of special technical questions four Panels have been appointed, and they deal respectively with stability and control, airships, airscrews and design. Each Panel has kept in touch with the experimental work on the various subjects, and from time to time has recommended an order of priority for the various experiments to be carried out at the Government establishments.

Meetings have normally been fixed a week previous to those of the Main Committee so that a monthly report could be presented dealing with the work of the previous month. The more important papers have been recommended for issue and, after approval by the Main Committee, have been printed and published by H.M. Stationery Office.

Fluid motion.—Theoretical investigations on fluid motion have been in progress, but owing to the inherent difficulty of the subject no great advance can be reported. Solutions by a graphical method have been shown to be possible for the equations of viscous flow, but these have not yet been published. An important paper on the conditions of flow at the boundary of the fluid in turbulent motion has been issued. Observations were made on air flowing through long pipes of circular section at various rates of flow, the range in experimental conditions being varied from $vl/\nu = 460$ to $vl/\nu = 325{,}000$. It is concluded from these experiments that for a large range of speeds above that for critical flow there is a thin layer of fluid at the boundary which is in regular laminar motion. This conclusion is of general interest as it has not been previously demonstrated.

Wind channels.—A new duplex wind channel of cross section 14 ft. × 7 ft. is now in working order at the N.P.L. Preliminary tests of its steadiness and uniformity of flow have been made, and it is considered to be at least as satisfactory as any of the previous channels erected at the N.P.L. This result encourages confidence in the erection of honeycomb walls across the buildings containing wind channels with a view to obtaining increased steadiness, thus making possible a decrease in the length of the distributor end of the wind channel. It is also now evident that for a given size of room the addition of a honeycomb wall erected across the containing room gives a steadier flow in the channel.

The Committee have discussed a new method of testing models in wind channels involving the construction of a return circuit type of channel to be run with the air under high pressure. By its use, results at a much greater value of vl than the ordinary wind channel can be obtained, but owing to the difficulties of model construction and of force measurement in this method, the lift being of the order of 800 lbs. on a model of 3 sq. ft. wing area, it is not considered that it would prove satisfactory.

The closed circuit type of wind channel in use at Göttingen has also been discussed. Its experimental portion consists of an open jet passing through the air in the building from a nozzle to a collector. It has the advantage that a model, relatively large compared with the size of the channel, can be tested at a pressure which is the same as that of the surrounding atmosphere. In other respects, such as steadiness, the channel compares satisfactorily with the N.P.L. type, but the methods of measurement of the forces on the model are possibly not so accurate as those in use at the N.P.L.

Complete aeroplane models.—In accordance with the previous decision made by the Air Ministry that complete models of all new designs of aeroplanes should be supplied to the N.P.L., a number of tests were made on a series of aeroplane and seaplane models. A report on these tests has now been issued, in which comparison is made of the longitudinal stability of the various types. A common curve is found to be quite satisfactory for five of the machines as giving the ratio of the change of moment for 1° change of the angle of incidence of elevator and tail plotted against the product of the respective areas and of the distances between the C.G. of the aeroplane and centres of area. This conclusion if applicable to other designs will be of value. The magnitudes of the derivative M_q* for the different machines have been compared with the theoretical formula given in another report, and good agreement is obtained. Consequently it would appear that this important derivative could now be calculated with a reasonable accuracy in most cases. Similar experiments are to be continued during the next year in order to ascertain the characteristics for lateral stability.

*The rate of change of pitching moment due to pitching.

Wind channel experiments have been made on the Tarrant "Tabor" with a view to explaining the accident on this machine. These experiments suggest that the machine would have been satisfactorily stable at all speeds except the actual stalling speed, and that it is probable the accident occurred owing to the opening out of the upper engines. In point of fact, although almost completely air borne at the time of the accident, the aeroplane never left the ground. There still remain, however, certain discrepancies between the observations of eye-witnesses and the prediction from channel experiments, and these matters are under investigation by the Accidents Sub-Committee.

In addition to the above, a few tests have been made on other types of machine. These include the Dreadnought Monoplane and the Fairey Type XXI Napier Lion.

Stability.—A useful summary of the present state of knowledge with regard to stability and control has been prepared at the Royal Aircraft Establishment for publication. It gives references to all the important papers dealing with the subject, both as regards longitudinal and lateral stability, static and dynamic control, measurements of stability derivatives and the effect of downwash and slipstream on control surfaces.

Attention has been paid to the analysis of the control motion of an aeroplane with a view to investigating the limitations of the controls and the part they play in modifying stability. A number of problems have been attacked and work on this matter is still in progress. It is of interest in view of the close alliance between the theory of the stability of aeroplanes and the modifications of an aeroplane's motions due to the movements of the various controls.

Some discussion has taken place as to the theoretical basis of the formula for the important derivative M_q, the rate of change of pitching moment due to pitching. Wind channel experiments as at present carried out give values which are too large by a certain factor dependent on the slope of the curve of downwash plotted against the angle of incidence. Attention has been drawn to an outstanding discrepancy in the prediction of the damping factor in phugoids, and it is hoped that the differences can now be accounted for. A report summarising the position has been issued.

Airscrews.—The most important work on airscrews that has been completed during the past year is an investigation into the distribution of pressure over the entire surface of an airscrew blade. For comparison with the thrust and torque curves as directly measured on an airscrew blade, the aerofoils corresponding to the sections on which the pressures were measured have been tested in the wind channel, both for the forces and for the pressures at the various points on the surface. By a comparison of existing theory with the wind channel measurements thus obtained, it has been found that the predicted and measured

values of the thrust are in good agreement. In the case of the values of the torque, the outstanding difference amounts to about 15 per cent., which, however, includes the frictional tangential forces for which no allowance has been made.

These pressure plotting experiments are at present incomplete for design purposes, but the R.A.E. has already constructed apparatus suitable for measuring the pressures in flight on an airscrew of identical design. When these are complete it should be possible to state how much of the scale effect between model tests and full-scale experiments is due to pressure and how much to skin friction.

On the completion of these pressure plotting experiments the N.P.L. has commenced tests on a family of five airscrews of various pitch diameter ratios, the screws being tested both as tractors and pushers, and as two-bladers and four-bladers. The family of airscrews has been designed on a basis having six sections common to all, which sections will be tested as aerofoils at a flow of VL as nearly as possible the same as in the airscrew experiments.

A number of tests on airscrews for the S.E.5 aeroplane have been completed at the R.A.E. They show that up to the highest tip speeds (880 ft./sec.) there is no evidence of the high speed affecting adversely the efficiency of the airscrew. High efficiency in level flight was obtained with quite small diameter airscrews, but for climbing the larger diameters are more effective.

With reference also to high tip speeds, further experiments on airscrews whose tip speeds approximate to that of the velocity of sound have been made at the R.A.E. Previous static tests suggested that the thrust was very small when the airscrew was running at such a speed that its tip speed approached the critical value. Later wind channel and flight experiments indicate that this is not the case under more normal conditions, but that the thrust increases in value with the speed of revolution.

With an airscrew running at high tip speeds no discontinuity in the sound emitted occurs as the tip speed velocity approaches and exceeds that of sound. Experiments on this matter at the R.A.E. have been described in a published report, and since that date Professor Bryan has communicated a paper on the acoustics of moving sources with application to airscrews suggesting a theory to account for the observed facts. The latter paper is mainly of theoretical interest, and forms a starting point for further work on the subject.

Dealing also with the sounds of airscrews is another published paper which describes experiments carried out in 1918 at the Butley Experimental Air Station. The range of audibility when an aeroplane was approaching up wind was measured both with and without an exhaust silencer fitted to the engine. No analysis of the sounds made was attempted, but comparison under different flying conditions of various types of aeroplanes were made with the

machines flying up wind. At low and medium speeds a gliding aeroplane makes very much less noise than one with the engine running, but no means was found of silencing the noise given out by the airscrew. It is evident that the problem of a silent aeroplane needs much further research before any approach to a solution can be expected.

Aeroplane control.—There is a lack of model experimental data on the control of aeroplanes flying at high angles of incidence, and to this attention has been recently drawn on account of the difficulty of controlling aeroplanes when about to land. Amongst the suggestions advanced for the improvement of lateral control at low speeds is the fitting of interplane ailerons and wind channel experiments show that the lateral control of an aeroplane should be greatly improved with the adoption of this type of aileron. Model experiments indicate that the tendency of all aeroplanes to spin when stalled, particularly if the ailerons are in use, may be greatly reduced by the substitution of the interplane aileron for the more usual type of lateral control. Flight experiments are now in preparation to verify this conclusion.

During the past year experiments have been completed on ailerons in which balance is obtained by placing the hinge some distance behind the leading edge of the aileron. The results obtained, together with full scale experience of the behaviour of these ailerons on a large aeroplane, indicate that this method of balancing is one which can be satisfactorily adopted for large machines. On the other hand, further special experiments made on horn-balanced ailerons show that if too near an approach to complete balance be made, the ailerons may under certain conditions of flight, particularly when side-slipping and making steeply banked turns, become overbalanced, and possibly, in a large machine, take charge of the control. Certain flying tests which have been made support this conclusion. Other model work on the balancing of ailerons has been the testing of the Avro method of balancing by means of small auxiliary balancing planes fitted above the ailerons forward of the hinge ; full scale tests of this method are also to be made.

In addition to the above experiments on ailerons, a few experiments have been made on the longitudinal control of aeroplanes. These include model experiments on elevators with various sizes of chord which agree well with previous full-scale experiments made at the R.A.E.

Airships.—During the past year it has been possible to carry out certain experiments on full-scale airships. They include turning trials on a number of ships, mooring trials and pressure plotting measurements over the upper fin and rudder of H.M. Airship R.32.

The pressure measurements on the fins and rudder of R.32 were taken under a variety of conditions, including normal

flight on turning trials, rapid manœuvres and other flights with the rudders locked in various positions. Model experiments to a scale of 1 in 44 have been made in the wind channel, but the values of the pressures thus measured are markedly lower than those on the airship in flight. The reason for this difference has not yet been ascertained.

With the increase in knowledge obtained from full-scale trials it has been possible to make direct comparison between stability characteristics as predicted from the model and the observations made in flight. In this connection the experiments on R.29 are of interest, and it is found that the model experiments are in good accordance with full-scale. Analysis of this work suggests the constancy of the product of the angle of yaw and the radius of the turning circle (R. β). Further experiments are needed to confirm the constancy of this product, which may prove of considerable value for performance prediction in turning trials.

Other experiments of interest are those on a model of the airship R.38, undertaken in order to obtain information regarding the aerodynamic efficiency of this ship. It was found that the resistance compares unfavourably with that of R.33, and the fins were also less efficient than those on the latter ship. On the other hand, an examination of the stability and controllability shows that the airship R.38 is a decided improvement upon the airship R.33.

The full-scale experiments on airships have to some extent been intermittent, as it was only possible to make flights when these ships could be spared from other work. It is hoped that one ship may be allocated specifically for full-scale research, as until this is done it will not be possible to arrive at any definite conclusion as to the scale effect between the airship and its model, or to clear up many of the outstanding problems in aerodynamic theory. Satisfactory progress in design and construction is to a large extent dependent on such information.

The mooring of airships is a question of special interest to civil aviation. Mooring trials at a mast are being carried out on R.33, and certain theoretical work on the matter has been done to assist the Air Ministry. Attention has also been paid to the various types of cable mooring, and a new system (Mark V) has been evolved suitable for the 33 Class ship. It is a three-wire system of mooring, in which three short "airship cables" are attached at one end to the mooring swivel of the airship, and at the other ends to rings spliced in a continuous ground cable which passes round blocks connected to the ground by short strops at three points of a triangular base. The method renders the top legs steep enough to clear the airship's forward car. The system is such that it can be picked up by the ship much

more easily than any of the former systems in which it was necessary to hoist a considerable weight of wire up to the airship. The three ship cables are carried in the ship, but involve no serious weight.

Kite balloons.—For meteorological purposes a special design of kite balloon has been completed to carry self-recording instruments to heights of about 10,000 feet. This type of balloon has not yet been tried out.

The amount of wind channel work on kite balloons has been limited to investigations of wind forces and moments acting on models of 1/50th scale. From these experiments it is inferred that the streamline fins of the same elevational area as the Caquot variety induce a smaller drag force, but are less effective as controlling surfaces. A discussion of the stability constants, as tabulated in the N.P.L. report on this matter, is deferred until the completion of an investigation into the general stability of the Caquot kite balloon which is now in progress.

Aeroplane wings.—A report on the development of aerofoil theory has been published by the Committee. It deals mainly with the work of Prof. Prandtl at Göttingen on the application of the theory derived from aerofoils of infinite span to biplane wing structures, and other matters which are of use for the direct prediction of the aerofoil characteristics on the full-scale aeroplane. The theory is based on the assumption of a given circulation imposed on the flow over the wing. [This has been previously suggested in "Lanchester's Aerodynamics."] The theory is considered to form an excellent basis for future progress in the prediction of the characteristics of aeroplane wings.

The design of new sections has received attention, but the most outstanding development has been the invention by Mr. Handley Page of a wing having a gap not far from the leading edge. Experiments on this type of wing show that it has a very high lifting power.

Bearing on the above question are a number of high lift sections reported in the German publication "Technische Berichte," Vols. I and II. The results for the most striking sections have been summarised and compared with the British sections R.A.F.15 and 19, in a report published by the Committee. They show that the best of the German high speed wings give very similar results to R.A.F.15, and the high lift sections are slightly superior (on model results) to R.A.F.19.

Apart from an increase of maximum lift by special designs of section, variable camber wings provide another means of increasing the speed range of aeroplanes. Tests have been made at the R.A.E. on a wing with hinged leading and trailing flaps, which show that by its use the speed range can be greatly increased. Without allowing for the weight of additional

structure, the stalling speed can be reduced by about 23 per cent., and the landing distance reduced approximately 50 per cent. The use of both flaps gives a resulting wing the movement of whose centre of pressure is not abnormal, as is the case with wings having a trailing flap only. It is hoped that full-scale experiments on a similar variable camber wing will be made so as to confirm, or otherwise, the wind channel results.

Other work is in progress on the aerodynamic properties of thick aerofoils suitable for internal bracing. The German Junker aeroplane and the latest design of Fokker employ this type of construction; so also does a new design under construction at the request of the Air Ministry. Before there is much flying in this country on these designs, it is desirable that model experiments should be made, and these are now in hand; in particular, it has been found that these monoplanes are very liable to spin, and it is hoped that model experiments will show how this tendency can be counteracted.

Concerning the spinning of aeroplanes, a complete report summarising all the available data, both theoretical and experimental, has been issued. To this report reference should be made for details.

Full-scale work.—Routine work, including full-scale tests on various modifications of aeroplane design, has been in progress throughout the year at the R.A.E., and the results of completed tests have been published. The more important include the tests on the R.A.F. 15 and 18 wing sections for comparison with model work, and they show a scale effect of the same order of magnitude as that previously obtained on the B.E. aeroplane and reported by the Scale Effect Sub-Committee (*see* R. & M. 374).

In addition to such tests, attention has been paid to several other matters directly concerned with the pilot's point of view. Two papers are of special interest. The first gives a comparison of the flying qualities of single and twin-engined aeroplanes, and discusses the effect of the engines on the aeroplane, particularly with reference to starting or failure. The influence of the engines is equivalent to an additional control which is not entirely independent of all others. These and other matters incidental to the difficulties of flying twin-engined aeroplanes have been carefully considered, and it is felt that the twin-engined aeroplane is not a machine which will be greatly developed in the near future. It is expected that, instead, a multi-engined aeroplane, driving a single propeller on a central thrust line, will be a more logical development. In the other paper, attention is drawn to the different needs of military and civil pilots. A quick response to the controls is a first essential for the fighting aeroplane and it is accordingly designed to be nearly neutrally stable. Civil requirements are to some extent contrary, as, safety being the prime necessity, a margin of stability is needed.

Amongst other questions discussed and reported upon are the determination of the maximum angular velocity of aeroplanes ; the distance required to take off an aeroplane ; an analysis of the component weights of aeroplanes, and an experimental investigation into the cause of rafwire vibration. This last has been an extensive research, and shows that the singing of the wires is due mainly to torsional vibration. The vibrations in themselves are not considered dangerous, but when the stress exceeds the breaking strain, the vibration is believed to determine the point and method of the fracture. Another note by the N.P.L. on the same question suggests that in the case of short wires the periods of the eddies given off determine the frequency of the note emitted.

Strength of construction.—Papers relating to the strength of construction of aeroplanes have been mainly directed to the important question of the determination of load factors. Various points of view have been presented as providing a different basis from that outlined in the Schedule of Load Factors issued by the Load Factors Sub-Committee in January, 1920. It has been suggested that the load factor should be dependent on an acceleration factor and a factor of safety. Another suggestion is the division of aircraft into classes based on a weight per horse-power.

The above matters are now being considered by the Load Factors Sub-Committee in conjunction with the aeronautical designers. In the meantime the design panel of the Aerodynamics Sub-Committee have discussed several papers on the methods of the determination of the strength of structures for different types of loading, including the particular case of an aeroplane diving vertically. If the pilot be assumed to have strength sufficient to use the maximum amount of control, it is possible for him to break his aeroplane. Under such conditions a fractional factor is considered, and calculations of the amount of this factor under a number of conditions have been made. Another important question is that of the side loads of the fuselage during flight, and here again certain papers have been published on the matter. The general question of combined side load and torsion is also receiving consideration.

Seaplanes.—Flying tests have been made on a seaplane of the F type in order to take measurements of the maximum loading in different parts of the hull bottom of a flying boat. Measurements were made during taxi runs, settling on and getting off the water at different speeds. In the early experiments an H.3 hull was used, but after this hull was damaged the N.16 was substituted. The pressure which was measured was of the order of 6 lbs./in.^{2}, but with normal landings in smooth water the forces experienced were less than 4 lbs./in.^{2} in all positions,

though a value of 8·7 lbs./in.^{2} was reached over a small area when landing at high speeds in rough weather. Arrangements have now been made to carry out a few additional full-scale experiments on a P form of boat, as this latter has a more flexible form of construction than the F type and may be subject to smaller external pressure on the hull.

In addition to the above work, the staff of the William Froude National Tank have made experiments on the loading up of a float of given beam. Various loadings were tried and limits to its amount were determined for given widths of beam. In all cases the maximum E.H.P. increased with decrease in beam. With reference to the same experiments, the size of the rear step was found to be unimportant, and the effect of tilting up the whole of the forebody relative to the tail did not affect the longitudinal stability at high speeds. Another test on the division of total load and resistance between the forebody and the afterbody was made, and it was found that the major portion of the total resistance was contributed by the former.

Internal Combustion Engines.

Engine Sub-Committee.—During the past year research work on internal combustion engines, at the Royal Aircraft Establishment, at the National Physical Laboratory and at the Air Ministry Laboratory, South Kensington, has proceeded under the direction of the Engine Sub-Committee, and for the discussion of this work the Sub-Committee have met monthly.

At the R.A.E. attention has been paid to the more general problems affecting routine testing in addition to special problems such as those connected with work on high flash point fuels, direct injection and ignition problems. Work has also proceeded on matters directly affecting fire prevention, to which reference is made in another section of this Supplement. At the N.P.L. a lengthy research on detonation has been commenced on lines laid down by Sir Dugald Clerk, who has taken much interest in this increasingly important question. Certain questions have also been referred by the Director of Research to the staff of the Air Ministry Laboratory, including a consideration of the existing position respecting the internal combustion engine turbine, experiments on engines, air flow meters and other matters.

In developing a programme of research the Sub-Committee have had in mind a most urgent question, viz., the reliability of the engines and power plants in aircraft. For the consideration of questions bearing on this problem a special Panel has been appointed and has suggested experiments for the elucidation of some of the problems affecting reliability. In particular, the Director of Research is having an analysis made of a large number of engine failures.

For future development it is proposed to proceed with a multi-cylinder high compression engine, to discuss the design of an engine developing high power at altitude, to consider the possibilities of a high speed aircraft engine and to investigate the use of high boiling liquids and water under pressure as cooling media.

Reliability.—The Reliability Panel was appointed to examine and report as to what steps should now be taken to develop a reliable engine for civil aviation purposes. After discussion they recommended that the Air Ministry should make the necessary arrangements to analyse and issue in a collected form, for the information of engine constructors, their experience as users of engines, as regards points affecting reliability; and further, that the necessary organisation should be established for carrying on the collection and issue of such information in the future. In particular, the information as to "epidemic" causes of failure which have occurred at various times, should be tabulated, together with as much information as possible as to the circumstances under which such failures have occurred. The Panel have also recommended that the Air Ministry should carry out reliability trials on a number of engines which would be of German manufacture when British types were not available, of as many different types as possible, two of each type being used.

The analysis suggested in the first recommendation is in progress. With reference to the second recommendation, four German engines, a selection of a number now at the R.A.E., have been chosen, and the Director of Research has instructed the R.A.E. to put them through the new type tests approved by the Air Ministry for British designs of engine. It is hoped that from these tests and corresponding ones on British engines information will shortly be available as to how improvements in design can be expected to lead to increase in reliability.

Detonation.—A number of papers dealing with the problem of detonation in aero engines have been received and discussed. The Staff at the N.P.L. are now in a position to conduct a series of experiments on the effect of pressure and temperature on the occurrence of detonation in explosive mixtures.

Detonation has been experienced in the small tube between the explosion chamber and the recording diaphragm, but this has been overcome by placing the latter in the surface of the experimental vessel. This experience raises the interesting question whether detonation in a restricted volume such as a small pocket at the sparking plug is a cause of detonation in the vessel, and this matter will be investigated. Slow rates of burning of the mixture prior to its complete ignition have

been observed, but it is hoped to minimise the effect by speeding up the rate of filling the experimental chamber.

For immediate progress, the N.P.L. will proceed to investigate the effect of turbulence on detonation, using a small fan situated inside the experimental cylinder: also the effect of adding oxygen to the air of the mixture until the point is reached at which detonation occurs. Other suggestions for future research include the investigation of the effect of a single sudden compression of the explosive mixture and the effect of the rate of revolution on detonation.

Mr. Ricardo has submitted a paper on the same subject, in which he draws attention to the small amount of inert gas which is required to check detonation. He is of opinion that about 5 per cent. by weight of the exhaust gas is sufficient to enable a compression ratio of 5 : 1 to be raised to 6 : 1 while at the same time increasing the thermal efficiency from 31 to 33. Mr. Ricardo also advances the opinion that prolonged detonation is liable to give rise to a crystalline effect in engine cylinders, an effect which he proposed to investigate further.

Electric air-flow meter.—The Sub-Committee have received a report on the Callendar air-flow meter which has been developed at the Air Ministry Laboratory, South Kensington. The instrument records by an electrical method the mean air-flow along a tube, and could readily be adapted to measure the flow in the induction pipe of an aero engine. It is expected that the chief advantage of its use would be for estimating the performance of engines at high altitudes, and it has been recommended that it should be tried in flight as the meter promises a better method of measuring the total air-flow than the now commonly used air box.

A further report on the same meter has been received from the Air Ministry Laboratory, giving records of the air vibrations in engine intake pipes. The Callendar electric air-flow meter was found to give an accurate measurement of the amount of air passing through the pipe in all cases except when the flow reversed. The meter is being developed by Professor Callendar at the Royal College of Science.

Variable valve timing.—With the increase of compression ratio and the introduction of super-charged engines, any device which will assist economy or increase power is of value. Amongst such devices may be noted variable valve timing which has a direct application to engine control at low altitudes. A delay in the closing of the inlet valve of an internal combustion engine gives a lighter charge in the cylinder, with a consequent less chance of detonation, and greater safety in running for a high expansion engine at ground level. The use of the device gives an estimated increase of about 15 per cent. in the available

power and an economy of about 7 per cent. in fuel at half load at ground level.

The experiments to date have all been made on single cylinder units, and the Sub-Committee have under consideration what tests can be recommended for future research with a view to the future development of a design of engine embodying a variable valve timing controlled either by a special set of cams or separate inlet valves. It is possible that preliminary experiments will be made on the modification of some existing design of aero engine such as the Semi-Sikh.

Torque reactions in aero engines.—The Director of Research has brought to the attention of the Sub-Committee the two following desiderata with reference to the general vibration of aero engines, (*a*) to design high performance aero engines with the practical certainty that serious synchronous vibration shall not occur in important units, and (*b*) to instal these engines in machines in a manner which will obviate serious vibration.

In reply to (*a*), it has been stated that it is at present very difficult to formulate rules for avoiding synchronous vibration but that it is possible to calculate from the completed design of an engine whether synchronism would occur or not. In reply to (*b*), it is uncertain whether engines can be always installed to avoid serious vibration.

Bearing on the above matter, a memorandum on a comparison of torque reactions in various types of engines has been received from the Directorate. In it calculations are made of the torque reactions due to fluid pressures in various types of engines. It is also understood that further theoretical work is in progress on the vibration of engines under various conditions, and it is hoped with the accumulation of further experience to give later more definite answers to the questions formulated by the Director of Research.

Ignition.—The Sub-Committee have given considerable attention to the subject of the magneto with special reference to the problem of eliminating trouble due to sparking across the safety gap at high altitudes, and to the question of the comparative qualities of British and German magnetos.

The former generally arises through the safety gap sparking voltage diminishing more rapidly with reduced pressure (*i.e.*, with increased altitude) than the sparking plug voltage, coupled possibly with increased plug voltage due to the engine becoming cold after shutting off at high altitudes. The most serious case, as regards sparking across the safety gap, is that of the engine with super-compression, in which the compression pressure is maintained regardless of altitude.

No really satisfactory and simple solution of the above difficulty has yet been put forward. Probably the most practicable method suggested is to have one side of the spark gap fixed and the other attached to a small Bourdon tube. The gap length can then be made virtually to vary with the air pressure. Another method is to have the safety gap enclosed in a liquid of high dielectric strength, and enquiry is to be made as to the possibility of a suitable liquid being found. Pure water has been considered, but it is thought that it would be impossible to maintain the very high requisite degree of purity for any length of time.

The Director of Research has presented a paper from the R.A.E. on "The relationship between the number of secondary turns on a magneto armature, and the secondary voltage with shunted resistance." This paper describes the continuation of an investigation reported previously in which it was shown that the sparking performance of an inductor type of magneto with shunted resistance could be improved 45 to 60 per cent. by reducing the secondary turns from the standard number of 10,000 to 7,000. The present paper extends the observations to a rotating armature magneto (Bosch D.U.4) and the results show that the optimum number of secondary turns is 7,200 as against the standard 8,400; the average increased performance is 11 per cent. while the shape of the slow speed characteristic is practically unaltered. The shunted secondary capacity characteristic shows an increased performance of 12 per cent.

Test beds.—It is hoped during the forthcoming year to carry out a certain number of researches at Universities, and other technical bodies, under the direction of the Committee. For this purpose it was necessary to consider various designs of test bed, of which the Ricardo unit promises to prove the most useful, and has been recommended for the purpose to the Air Ministry.

The Ricardo unit was designed primarily for fuel research, and consists of a single cylinder unit of $4\frac{1}{2}$-in. bore and 8-in. stroke, the main features of the design being :—

(1) The provision of means for varying the ratio of compression in the shortest possible time, and that while the engine is running on full load.

(2) The ability to run for long periods at piston speeds of from 2,000 ft. to 3,000 ft. per minute.

(3) The application of every known expedient in order to obtain the highest possible thermal, volumetric, and mechanical efficiency.

(4) The provision of testing gear designed with a view to ease and rapidity of operation and the elimination as far as possible of the personal equation.

The most important consideration of all, however, was the attainment not only of reliability in the sense of freedom from breakdowns, but rather in the sense of mechanical consistency.

For other work the R.A.E. are developing a design of universal test bed suitable for the universal fitting of different types and sizes of cylinder. The unit has not yet proceeded beyond the design stage, but two sets are to be constructed to try out completely the whole design.

High altitude test chamber.—For the development of high altitude flying it is essential to have a suitable chamber for testing engines under conditions approximating to those at high altitudes. A new high altitude test house is shortly to be erected at the R.A.E., as the existing plant is inadequate to test present day engines with satisfactory results.

The plant is designed to test a normal engine of about 300 h.p., the power of which varies approximately as the pressure of the surrounding atmosphere, under altitude conditions equivalent to 30,000 ft., or alternatively, to test a supercharger engine of about 260 h.p. in which the power is approximately constant and independent of altitude.

The general scheme is to convert the two existing end beds (1,200 and 800 h.p.) at the R.A.E., so that they will be suitable for making tests under altitude conditions, and to extend the present building to house the necessary auxiliaries. The plant would be arranged so that future expansion beyond the auxiliary plant is possible.

The chief new plant required would consist of vacuum cubicles for containing the engine under test, pumps for evacuating the exhaust and engine cubicles, and refrigerating plant for cooling the carburetter air supply.

The internal combustion turbine.—While paying attention to the piston engine the Committee have also considered the possibilities of the gas turbine for air work. A report from the Air Ministry Laboratory summarising all the published data on the internal combustion turbine has been communicated by the Director of Research. In it full details are given of the various types of turbine which have been designed and the results of calculations show in what respects each design fails to give an efficiency comparable with that of the internal combustion piston engine.

It is evident that the internal combustion turbine is not yet a practical proposition for use in aircraft, as its overall efficiency cannot be high because of the low thermal efficiency of the working cycle. In some respects the steam turbine is more likely to be successful in aircraft development as a greater efficiency is obtainable, although it will be necessary to develop elaborate condensing arrangements, especially for use during the period when an aeroplane is starting up on the ground.

Meteorology.

Meteorology Sub-Committee.—The Meteorology Sub-Committee has held ten meetings during the past year.

The Sub-Committee was reconstituted on the appointment of the Aeronautical Research Committee in May, 1920, to consider meteorological questions, and now includes in its purview matters relating to navigation and to atmospheric electricity. Navigation has become, with the advent of civilisation, a very important branch of aeronautical science, and to it the Sub-Committee have paid close attention. Atmospheric electricity is a subject having a bearing on meteorology, and was formerly dealt with by a special committee appointed by the Advisory Committee for Aeronautics.

The function of the Sub-Committee is, on the one hand, to answer any questions concerning general meteorology, atmospheric electricity and navigation that arise in the course of the experience of the R.A.F. and others, to promote the use by airmen of a scientific knowledge of meteorology, aerial navigation and atmospheric electricity, and to offer suggestions for the improvement of that knowledge and of the current forms in which it is presented for the use of airmen; and, on the other, to suggest means by which additional data for the increase of knowledge can be obtained by airmen in the course of their employment.

The suggestions for the extension of knowledge by new forms of observations or by experimental researches in so far as they are not dependent upon the personal contribution of members have been made to the Committee in communications from the Director of the Meteorological Office, the Director of Research and the Director of the N.P.L. respectively; and, per contra, the Sub-Committee have considered questions concerning meteorology, navigation or atmospheric electricity upon which the directors may desire the Sub-Committee's assistance.

The aspects of the subject to which the attention of the Committee has been directed in the first instance are :—

1. The present position of our knowledge of the structure of the atmosphere in relation to the requirements of airmen traversing the various air routes.

2. The information which is required for the purposes of navigation by dead reckoning in addition to that which is already currently available and the means by which it can be obtained.

3. The particular questions which have come up immediately for consideration :—

(*a*) The extent to which local observations of atmospheric structure can be relied upon for indicating conditions in other localities and at subsequent times.

(*b*) The study of the relation of local changes in the stratification of drift to cloud layers, inversions, and other notable conditions of stratification.

(*c*) The construction of charts of distribution of pressure and wind at different levels from the data already available, and the means for bringing them up to the necessary standard of fulness and accuracy.

4. The improvement of meteorological instruments used in aerodromes or on aircraft. The instruments already considered are (*a*) the aneroid barometer, (*b*) various forms of anemometer, (*c*) the barothermograph.

5. *Navigational instruments and methods.* The instruments already considered are (*a*) the sextant, (*b*) compass, (*c*) turn-indicator, (*d*) airspeed indicator, (*e*) air log; and for methods, the following are under consideration :—(*a*) The use of the gyroscope, and (*b*) direction-finding for aircraft.

6. Atmospheric electricity, including (*a*) further consideration of the electrical conditions in thunderstorms and the protection of aircraft from lightning; and (*b*) location of thunderstorms by directional wireless telegraphy.

7. Meteorological log for aircraft. This is in connection with the forms already approved and previously mentioned in the last annual report.

Structure of the atmosphere.—For successful aerial navigation it is essential to be able to obtain information from time to time of the structure of the atmosphere at different altitudes, and for this purpose the kite balloon seems eminently suitable. A special panel of the Sub-Committee held meetings to discuss this matter, particularly with a view to the determination of the magnitude and direction of the wind at heights, and a scheme has been drafted and forwarded to the Air Ministry.

It has been suggested that a number of unmanned kite balloons should carry recording instruments to obtain regular information of wind, cloud level and temperature up to a height of 10,000 feet. In order to obtain information as to the practicability of the kite balloon method it would first have to be tested at a single station. To obtain data for analysis it has been recommended that kite balloons should make three ascents daily.

A successful self-recording instrument for use on kite balloons has been designed at the R.A.E. By it a very satisfactory record can be obtained of the wind direction and magnitude, the altitude

and the temperature at definite times or intervals thereof. A memorandum describing this instrument has been published.

The employment of a kite balloon as here proposed promises better results than any other adopted method, such as the use of free balloons, observations of anti-aircraft fire and other means, on account of its independence of cloud and mist. It is understood that the Air Ministry are proceeding to develop the scheme.

Bearing also on general meteorological questions is an important paper communicated by the Chairman on the cyclonic depressions of middle latitudes in the form of a note on a conference between Scandinavian and British meteorologists held at Bergen in July, 1920. The communication refers to a new method of forecasting by a detailed study of the polar front in cyclonic areas, and deals with the analysis of the distribution of pressure at the surface in two layers with opposite circulations, one due to distribution of temperature in the surface layer with east to west circulation, and the other due to the distribution of temperature in the upper air with west to east circulation. Calculations are made in connection with a hypothesis of the supposed gradual descent of air in an Atlantic anticyclone, and show that a rate of drop of 80 metres per day is sufficient to provide the flow of air from the typical distribution of pressure in a north Atlantic chart ; the above figure is equivalent to the transposition of the air from the top to the bottom of the anticyclone in about 100 to 130 days. A theory of the structure of cyclonic disturbances caused by the eviction of fluid from air in relative motion is also considered with special reference to tropical storms. A table of correlation-coefficients between changes of pressure and changes of temperature at different levels of the atmosphere in England is included in the paper and shows what a high correlation exists between these two important physical characteristics of the atmosphere.

The convection hypothesis put into modern form suggests that the equilibrium of the atmosphere at some given place becomes neutral and later unstable. At this place saturated air commences to rise, and continues to do so until it reaches a height where equilibrium is possible, the height and rate of rise being determined by the difference between the lapse rate of the saturated air and that of the air through which the ascending column is passing. The replacement of this ascending air by other air flowing in laterally indirectly causes the depression. This hypothesis has been discredited in modern meteorology because the interior core of a cyclonic depression has been ascertained to be colder than its environment. But if the rising air carries with it a part of the environment the loss of materials represented by the reduction of pressure may be accounted for.

A theory of the formation of cyclones has been suggested as a result of the discussions on this paper and of an enquiry into the preceding history of the subject. Convection is considered to be probably the first cause of the main pressure distribution over the world, due to the difference of temperature at the poles and equator. Later, at various times and in divers places, local eddies occur forming ultimately by combination large cyclones which obtain their potential energy from the general pressure distribution.

Fog.—The difficulties attendant on the use of aerodromes by aeroplanes when a fog enshrouds the ground are amongst the most troublesome of those with which civil aviation in this country has to deal. There are two aspects of the problem, the first dealing with the landing of aeroplanes by the employment of various devices independent of the state of the atmosphere, and the second with methods of clearing fog from large areas.

Concerning the latter, the possible means of dispersing fog can be briefly summarised under three heads: (1) electrical, (2) mechanical, and (3) thermal methods. With our present knowledge none of these gives a solution to the problem of clearing an aerodrome of fog.

As an electrical discharge from a point does not spread over any appreciable volume of air, and as the free paths of the normal small fog particles are very great in comparison with their size, electrical methods do not at present give much hope for a solution of the problem of fog dissipation by such means. All methods for discharging large quantities of electricity into the atmosphere fail largely on account of the small volume of air affected. In the case of small volumes it is easy to show as a laboratory experiment, how, say, a 50 cc. flask can be cleared of fog, but the extension to a 50 litres flask, using a 2-in. spark, presents more difficulty, the time for clearing increasing very rapidly with the size of vessel.

With reference to the mechanical method, an estimate has been made of the power required to "drain" away the lower fog-bound air of an aerodrome at such a rate that the air over the aerodrome is kept clear by the fresh supply from above, in spite of the tendency of the fog to encroach from the sides. Suppose that in an aerodrome of 1 kilometre square it is necessary to drain the air at a rate involving a downward velocity of 1 metre per min., then about $1{\cdot}2 \times 10^6$ kilograms of air will have to be removed each minute. This could be done by about 50 aeroplane propellers of about 2 metres diameter provided they could be designed so as to work as efficiently at zero advance as at

ordinary flight speeds. It is feared that the dissipation of fog by such mechanical means is not practicable.

The remaining possibility is the thermal method. Assuming that if the fog were warmed 5°F. it can be dispersed, then for an aerodrome some 400 yards wide with a thickness of 50 feet, and a drift of 4,000 yards in an hour, it can be shewn that 13 tons an hour might be the coal consumption, provided the heat generated could be directly used for the purpose in question. In practice it is probable that the consumption would be four or five times as great. This method does not accordingly show any greater promise of success than either of the others.

As affecting the landing of aeroplanes in fog, since it is considered impracticable to clear aerodromes of the fog, two methods to facilitate this manœuvre have been proposed. In the first, kite balloons would be placed at such a height that a pilot could set the elevators to glide with the natural gliding angle of the machine into the aerodrome. On approaching the ground, which would be visible at a height of about 20 feet—except in the densest fogs—the pilot could then flatten out his machine. It is understood that the Director of Research is making arrangements to try out this method in fine weather.

The other method which might prove suitable in misty weather is the employment of a leader cable which could be used for the landing of aeroplanes, by the use of some device which would light a lamp on an aeroplane when the craft was at a certain height above the ground. It is hoped that the Director of Research will be able to co-operate in experiments to try out the method, but the data available at present are scanty.

Although there is a certain amount of information as to the heights of fogs there are no statistical data on the relative frequencies of fogs of different heights. It is believed, however, that the upper limit of a fog is generally fairly well defined. It is agreed that the available information on the subject should be collected by the Meteorological Office and also that experiments using kite balloons for the purpose should be carried out.

Atmospheric turbulence.—Measurements of turbulence in the atmosphere near the ground have been made at the R.A.E. from the form of the spreading smoke from a factory chimney. In addition, an attempt has been made to measure turbulence with the aid of aeroplanes, by towing a smoke bomb on a long wire (about 150 ft.) below an aeroplane and measuring the rate at which the streak of smoke so produced spreads out laterally. The object of the experiments is to measure turbulence at various heights and to correlate the values with the temperature lapse rate and vertical wind-gradient. It was expected that eddies caused by the aeroplane would be damped out before they spread

to 150 feet below the aeroplane, but experiment has proved the contrary. It would be difficult to tow the smoke bomb at a greater distance below the aeroplane since increasing the length of wire would not greatly increase the vertical distance below the aeroplane without the use of an excessive weight. There is, however, one way in which measurements could be made free from all disturbance, viz., by fixing the smoke bomb to the cable of a kite balloon and photographing the smoke in the same way as was done in the case of the smoke from a factory chimney. A recommendation has accordingly been made to the Air Ministry to use, for further experiments on turbulence, the kite balloon which has recently been installed at Shoeburyness. The additional cost of the smoke bombs would be small, and an expert scientific staff is on the spot; the meteorograph would provide records of wind and temperature, so that all the information required would be available. In connection with this same matter it is now known that small eddies, of a character similar to that of a cyclone can be produced by pure convection, and it is of interest to note that air near the ground has a greater eddy coefficient in hot weather than in cold. Eddy motion, however, appears to exist at all altitudes. Observations of eddy viscosity in the atmosphere are, therefore, of practical importance.

Altimeters.—Some interesting information on the accuracy of altimeters has been communicated to the Sub-Committee, who find that the existing latitude allowed in instrumental design is far in excess of that obtainable by the best designs of instrument. Several altimeters recently tested at the R.A.E. show an error not greater than 1 mb. at the end of tests corresponding to flights at high altitudes. Accordingly the Air Ministry are considering whether the existing tolerances can be considerably narrowed with advantage.

The method of applying corrections to altimeters has been discussed. The French now use Toussaint's formula for correcting the graduations of altimeters so as to take account of the lapse rate of temperature, a correction which has only recently been introduced. Mr. Whipple, Superintendent of the Climatological Section, Meteorological Office, has proposed another formula which is in better agreement with observation in some parts of the vertical section through the atmosphere. In addition, there are available Mr. Dines' tables of mean observed values of pressure and height by which empirical formulæ must be tested.

In reply to an enquiry from the Air Ministry Committee for Standardisation of Altimeters, the Sub-Committee forwarded a copy of Mr. Dines' tables together with a second table showing the differences between the values of pressure at a given height, as given in the tables, and those calculated by Toussaint's formula. The former are the better, but the Sub-Committee were not in a

position to decide whether the differences were of sufficient importance to be regarded in the graduation of altimeters. The Sub-Committee have since been informed that the Toussaint formula has been adopted as the differences between the readings on this graduation and those on Mr. Dines' tables cannot be detected in practice.

The Air Ministry Laboratory at South Kensington have constructed an instrument which gives the corrections that have to be applied to the aneroid readings at different heights. The instrument has been calibrated for the constant temperature altimeter graduated for an isothermal atmosphere, but it can be easily modified for a uniform lapse rate. With reference to the latter the height correction will be proportional to temperature difference if Toussaint's formula or any other formula for uniform lapse rate be used for calibrating the height scales of aneroids; this is not the case with the first instrument.

Aerial Navigation.—A number of navigational flights have been made during the past year. One of the most successful was the 1,000 mile "Handley Page" navigation flight carried out in co-operation with the Instrument Design Section of the Directorate of Research. Mention should also be made of the navigational reports of the Trans-Atlantic and African flights. The very interesting information derived from the navigational reports of these flights shows the desirability of obtaining similar reports, if possible, for the other important flights recently accomplished, and in addition the meteorological reports which should be read in conjunction with them. It is of interest to note that in the African flight the navigator had the advantage of the latest designs of instruments, including the R.A.E. bubble sextant and an experimental form of Bygrave spherical triangle slide rule.

The "1,000 mile" flight was made to test instruments already in use, especially the R.A.E. bubble sextant, and to ascertain what accuracy could be obtained by dead reckoning methods. Good accuracy was obtained by "dead reckoning," but the sextant observations proved disappointing as they were sometimes only within about 17 miles of the correct positions. Observations made by means of flares dropped on to water were very successful, and this aid to navigation is considered most promising whether for use by day or night. The estimated winds as given in the tables of the report agree well with the data available at the Meteorological Office. Appended to the report of this flight is a list of instruments recommended by the writer for use when navigating this type of aeroplane.

A number of instruments, including the R.A.E. bubble sextant, have been tested in a navigational flight on the rigid airship R.33. The flight provided the interesting conclusion that for sextant work an airship is only slightly inferior to the ground.

Two reports presented by the Director of Research deal with the respective merits of the R.A.E. bubble sextant, Mark IIa, and the American (Willson) bubble sextant. Much the same accuracy is obtainable by the two instruments, the mean error of the latter being slightly less. It is expected that the new R.A.E. instrument which has been modified so that the horizon can be directly viewed, will meet all present needs until a suitable gyro sextant becomes available.

Another paper dealing with the methods of reduction of astronomical observations taken to determine position during flight has been received by the Air Ministry Laboratory. In it the various methods which have been suggested for solving spherical triangles are described, and of these the Bygrave slide rule was found to be the quickest for determining the position of an aircraft during flight. The usual nautical tables are considered too clumsy for navigation, and it is proposed to prepare a shorter form of table specially suitable for air work.

Compasses.—A valuable paper on aircraft compasses communicated by the Air Ministry Laboratory has since been published. Diagrams are given showing the various characteristics of most of the existing designs of compasses, and enable a direct comparison of any feature to be made between the different designs. The slow period compass has been found by past experiments at the R.A.E. to provide the best instrument for aeroplanes, but it has the disadvantage of a slow rate of damping for the oscillatory movements of the needle. Improvements to overcome this last have been suggested by Dr. Bennett, of Emmanuel College, Cambridge, so that it is hoped shortly to produce a slow period compass embodying the best features of both the slow and quick period compasses.

Fire Prevention on Heavier-than-Air Craft.

Fire Prevention Sub-Committee.—The Fire Prevention Sub-Committee has continued during the past year to analyse further the causes of fires on heavier-than-air craft, both in the air and on crash. The Air Ministry issued their preliminary report (C.I.M.747) in August, 1919, and later in April, 1920, a second report containing some further notes (I.M.1019) on fire prevention, which related mainly to an accumulation of experimental evidence bearing on the occurrence of fires in aeroplanes. Since this latter date the R.A.E. have, at the suggestion of the Sub-Committee, embodied in a Wasp-Avro aeroplane most of the recommendations of the Sub-Committee. This aeroplane can be viewed at the Establishment and a description of the machine is given in a published report (R. & M. 691) of the Research Committee.

The Sub-Committee's work can be roughly divided into a consideration of fires in the air, the risk of which—as has already been pointed out—is relatively small, and fires on crash. To the latter most attention has been paid, especially with a view to ascertaining all the possible causes of fire, and this has been accelerated by the experimental work conducted at the R.A.E. and the N.P.L. at the Committee's request.

The programme of experimental work has included :—

(1) Fire and high temperature tests on high tension cable sheathed in metal.

(2) Investigation of risks due to insufficient earthing of sheathed H.T. cable.

(3) Installation of Wasp engine in Avro aeroplane. Development of a safe system of engine installation generally.

(4) The running of petrol pipe systems ; metallic couplings for petrol pipes and the avoidance of rubber or other inflammable material under the cowl.

(5) Safety fuels, and the prevention of fire on crash due to spray and vapour.

(6) Research on crash resisting petrol tanks.

(7) Fire extinguishing apparatus.

(8) Fire-proof magnetos.

(9) Investigation of all causes of ignition of petrol vapour.

(10) Any other causes of fire.

Rearranged Avro aeroplane.—The rearranged Wasp-Avro aeroplane at the R.A.E. is of interest as embodying the various recommendations made by the Fire Prevention Sub-Committee from time to time. Its main features are as follows :—

Nearly all inflammable material has been removed from in front of the bulkhead, the only rubber parts being the magneto leads and the induction pipe connections. The magnetos have been placed in front of the engine near the airscrew and are easily accessible. All the engine supports have been constructed of metal, the engine itself being changed from a rotary to a radial type. An additional precaution has been taken in placing the petrol tanks out on the wings ; this necessitates having a high suction to meet which a pump capable of giving a suction equivalent to that necessary to draw petrol through 30 ft. of pipe is fitted. All metal joints have been fitted throughout, and the bulkhead constructed of an aluminium-asbestos sandwich, completely screening the engine from the rest of the aeroplane. The rearrangement of the aeroplane is intended to demonstrate that these precautions can be taken while keeping the engine and other parts readily accessible for alteration or inspection.

The metallic couplings for the petrol pipes have been flown for a large number of hours, and have proved quite satisfactory. A description of their main features is given in a published report (R. & M. 703). Two types of couplings have been experimented with at the R.A.E., namely, a flanged coupling and a " muff " coupling. The experiments tend to show that the flange type is superior. There is no sign of leakage after severe vibration tests, and apart from eliminating the inflammable rubber, it has been found that, as present types of fuel contain a high percentage of solvent which deteriorates the rubber and chokes the pipes, there is additional reason for avoiding the rubber joints. It should be noted that the metallic couplings necessitate the addition of coils of copper pipe at each joint, and possibly at other points between supports, to take up vibration, that the method of " spinning " to produce the flanges is replaced by "punching " the end of the pipe into shape, and that only good quality copper piping should be chosen for flanging. An improvement would result if pipe lines were standardised, and pipe lengths bent to template instead of being run in the ordinary way by the coppersmith. With regard to the vibration test, experiments are to be carried out on a section of piping having the mass of the joint midway between two supports, and thereafter that physical tests should be made of the piping near the supported points : this vibration test will be allowed to run for 100 hours. To try out the matter the Air Ministry are fitting a flight of aeroplanes with metallic couplings for all petrol pipes.

Another feature of this aeroplane is the installation of the petrol tanks in the wings. It is not yet certain whether the manœuvrability of aeroplanes would be appreciably affected if all petrol tanks were placed on the wings instead of in the body of the aeroplane, but experiments are in hand to investigate the matter. From the fire risk point of view, wing petrol tanks are desirable, for, whether in flight, on the ground, or during a crash, the risk of igniting a large quantity of petrol by any means is greatly reduced.

Special petrol tanks.—Another method of countering the risk due to the inflammability of petrol has been suggested, viz., to render the tanks crash-proof. To test the properties of a variety of tanks a derrick was erected at one corner of the R.A.E. aerodrome, so that the aeroplane tanks could be loosed along a guide wire from any height up to a height of about 45 feet from the ground. In the experiments the tanks were raised usually to a height of 25 feet, and then let go, so that they impinged on a derelict engine fixed in the ground. In later experiments a derelict fuselage fitted with engine and tank was dropped in a similar manner from the top of the derrick.

Tanks from a Sopwith Camel, D.H.9, and an Imber tank were partly filled with water to represent fuel weight and dropped, a few of the Sopwith tanks being fitted with special linings. The experiments demonstrated that ordinary tanks, including the Imber, were not so satisfactory as one which had an internal rubber bag containing the liquid, and an inner lining of felt to prevent the frayed metal surface from piercing it. The satisfactory results obtained with the last type which did not release the fluid on impact either from a 25 foot or 45 foot drop appear to indicate that when the difficulty of fitting pipes and fillers to the internal bag has been overcome, a useful line for evolving a suitable crashproof tank has been found. The extra weight, though considerable, compares favourably with the Imber tank. The experiments with the derelict fuselages showed that the tests with the tanks impinging on a derelict engine were probably more severe than would obtain in a crash.

The wind resistance of the petrol tanks on the wings has been found by experiment at the N.P.L. not to exceed about one per cent. and the loss of lift from tanks such as are fitted to the "Rearranged Avro" does not exceed two per cent. The difference in weight due to extra piping, fittings, additional structure, has not yet been ascertained, but a comparison of various designs is under consideration. In the above connection it is of interest to note that the Westland aeroplane, which won first prize in the 1920 open Government competition, had petrol tanks placed on the wings.

Ignition cables.—In addition to the danger of ignition by sparking from a magneto, a matter which has already been dealt with in the previous year's report by the institution of fire tests, the breakage of ignition cables gives a possible cause of fire. One way of meeting the latter would be to make the conducting part of the cable of high tension steel, the cable to be quite flexible, and with a large portion of slack between the attachments at any two points. Experiments show that the change in capacity as compared with a copper cable is negligible, while the possible effect of the sulphur in the vulcanised rubber on the steel could be overcome by using an additional covering between the rubber insulation and the steel cable.

In the case of aeroplanes fitted with a wireless installation, it is necessary that ignition cables should either be enclosed in a metal sheath or be covered by a metallic braiding. Experiments have been made at the R.A.E. to investigate the inflammability of the latter type of cable, and a type of covering has been found which will withstand a hot fire for several minutes before the rubber oozing between the strands of the braiding catches fire. As an alternative the use of a non-inflammable insulating material in place of the rubber or a shield in the form of a thin metallic

(aluminium) tube seems preferable. It may be here noted that the introduction of the metal braiding does not seriously deteriorate the behaviour of the magnetos.

The results of insufficient earthing of the metallic braiding is another matter that has received attention. The voltage existing between such braiding and "earth," induced by the high frequency oscillations in the ignition spark, is sufficient to cause a spark between braiding and "earth" capable of igniting an explosive mixture. For safety it is necessary that the braiding should be earthed close up to the magneto and sparking plug ends. Special terminals might be required to be fitted for this purpose, and it has been recommended that the scheme be tested on an aeroplane to ascertain how far the use of such earthing terminals is practicable.

Fireproof magnetos.—Next in order of importance as a cause of fire after the exhaust manifolds and pipes is the magneto. The Sub-Committee are discussing what are the essential matters in magneto design which are of importance for fire prevention and propose to draft a number of recommendations to cover the essential points. There are two methods of tackling the problem of a fireproof magneto : the first involves a special design and provides an installation which would be as perfect as possible ; and the other lays down a number of precautions, such as the sheathing and frequent earthing of the sheathing of the high tension wires, better methods of installation and more perfect fitting of parts, which *in toto* might well involve as many difficulties as the first, but would be more quickly applicable.

High flashpoint fuels.—As the presence of petrol with a low flash point constitutes one of the main fire risks, the Sub-Committee have discussed the use of a less inflammable fuel. A specification for a high flashpoint fuel has been drafted, the fuel to consist as far as possible of saturated hydrocarbons of the paraffin series, and to distil so that 95 per cent. was collected between 126°C. and 200°C. The flash point of Abel's test has been fixed at not less than 25°C.

A number of fuels to this specification have been tried in a single cylinder unit at the R.A.E. and have been found useable in the engine. With the best fuels about 6 to 8 per cent. decrease in power and an increase of fuel consumption from 5 to 20 per cent. was experienced. A difficulty associated with the use of these fuels is that of starting the engine, but this can probably be overcome. Flight tests are in progress.

Methods of ignition.—During the consideration of questions relating to the frequency of fires on crash the Sub-Committee were confronted with the following :—What are the possible methods of igniting petrol under the conditions obtaining in a

crash ? To elucidate this point the N.P.L. have conducted a number of experiments at the request of the Committee. They showed the ease with which small pieces of wood burst into flame at comparatively low temperatures ; this is thought to be a possible cause of fire after crash in cases when the outbreak is not instantaneous with the impact on the ground. It is evident from the N.P.L. report that none of the methods tried, most of which had given negative results, are likely to be sufficiently dangerous to account for the numerous fires occurring on crash, and that the Committee will have to look to other sources for the causes. Attention is also drawn to a " quantity " effect in the ignition of explosive mixtures ; for instance, an explosive mixture of petrol and air uniformly heated to a temperature of about 350°C. to 400°C. ignites spontaneously ; while on the other hand, the insertion of a hot wire which only gives local heating, does not ignite the mixture even if the temperature is considerably above this figure. It is possible that ionisation may be important in the case of ignition of explosive mixtures by a magneto spark. This investigation at the N.P.L. has covered the ground in so far as breakage of steel wires, &c., may be considered as causes of a fire.

The fire risk from hot exhaust pipes.—The chief risk of fire on crash is considered to be due to hot exhaust pipes. Attention has been drawn to a suggestion made by Professor Cormack to shield exhaust pipes so that petrol cannot be sprayed upon them in the event of a crash, and for this purpose the use of an asbestos covering or a thin metal shield was suggested. The Committee are of opinion that if the exhaust pipes are shielded in any way or covered with asbestos they will be hotter than when freely exposed to the air. If broken in a crash the danger from fire would be increased rather than diminished by such shields.

It is considered essential to keep the exhaust manifolds and pipes as cool as possible. Experiments made for the Committee show that petrol itself will not usually ignite when sprayed on the hot metal, but lubricating oil will do so, and the amount of inflammable vapour present will, of course, be increased if petrol reaches the hot pipes.

It has previously been reported that there is an excess of fires on aeroplanes with stationary as compared with the rotary engines. The existence of a hot exhaust manifold in the former may in some degree explain this, and generally the Sub-Committee consider that cooling of the manifold to 300°C. would decrease the fire risk.

To overcome the inherent difficulties of cooling an exhaust manifold, various suggestions have been brought forward including a method similar to that used by the Germans in which air is drawn over the exhaust pipe by the induction action of the

exhaust gases which are led into a larger concentric pipe opened at both ends to the atmosphere. This method also in some degree shelters the exhaust pipe from sprayed petrol, but the danger that the exhaust pipe will be hotter, and may be broken, remains. A suggestion which has been tried is the glazing of the inside of the exhaust pipes, but this proved unsuccessful due to the corrosion of the glaze by the exhaust gases, and further enquiry is on foot.

The use of thin gilled radiators fixed to both the exhaust manifold and the exhaust pipes has been proposed and recommended for early experiment. Such gills would cool the manifold and assist in more rapidly lowering the temperature after the engine had been cut off. The R.A.E. have been requested to consider a preliminary design for gills on a manifold of some engine which could be tried in flight with the intention that the temperature of the manifold should be maintained below the figure at which small chips, dried grass, &c., can be ignited (400°C.). It is understood that the firm of Boulton & Paul have a cast aluminium manifold provided with fins on one of their aeroplanes which will shortly be flown at Martlesham Heath. During its performance trials it is hoped to obtain temperature readings on these fins and on the manifold during flight ; also, the temperature some 10 seconds after the engine has been cut out. These measurements have been asked for.

The ignition of pieces of fabric falling on the exhaust pipes or other hot parts of the engine is considered to be a specially likely cause of fire, as the undoped portion of the edges of torn fabrics ignite at temperatures (200°C.) considerably lower than those for chips of wood, &c. Experiments show that small pieces of undoped fabric ignite when placed on the exhaust manifold of an engine a short time after the latter has been stopped. To overcome this risk it is recommended that the R.A.E. should make experiments with a view to finding a fireproof fabric whose weight will not be greatly in excess of ordinary doped fabric. In addition, the National Physical Laboratory have been asked and are finding the temperatures of ignition of the aeroplane dopes and fabrics in current use.

It may further be noted as the result of analysis of accidents over a long period that the numbers of fires on crash with stationary air-cooled and water-cooled engines are equal.

Fires in the air.—These have been shown to be rare. Such precautions as are possible to avoid their occurrence have already been embodied in previous recommendations, but there is one modification.

In their preliminary report, the Sub-Committee drew attention to the danger of fire from leaks in the exhaust manifolds and carburetter air intakes, and in accordance with their request the R.A.E. have made a number of tests to ascertain what pressures existing designs would stand. From the results of these tests

it is evident that good designs do not leak at a pressure of 20 lbs./in.^{2}, and the Sub-Committee accordingly propose to adopt this figure instead of 80 lbs./in.^{2} as a recommendation to the Air Ministry when they present their next report.

Materials and Chemistry.

Materials and Chemistry Sub-Committee.—This Sub-Committee has discussed details in connection with various materials of construction used in aircraft work. They met six times during the past year for the discussion of papers and to receive the report of Panels on special matters. Their work has been partly subdivided by the appointment of Panels on Elasticity and Fatigue, Light Alloys, and Fabrics and Dopes. In addition to the ordinary routine work they have prepared an extensive programme for research work to be carried out at Universities and other Technical Institutions, and for this work a special sum has been voted by the Air Ministry so that it can be carried out during the year 1921–22.

Programme of Work of the Sub-Committee.—In drafting a programme of work for research the Committee have had in mind only to include such items as can be accorded a high priority and for which a reasonable hope could be entertained either of completion or of very substantial progress during the coming financial year. Many investigations are already in hand.

In certain investigations, such as the effect of scratches and rapid changes of section on fatigue resistance, the work will be duplicated in different institutions. This, however, is only in special cases in which it is considered advisable that the particular work should be subdivided amongst several investigators, and in which no special apparatus is required beyond the ordinary equipment for fatigue testing. The careful supervision of the whole programme of work will effectively prevent overlapping.

In the National Physical Laboratory the fatigue ranges of steels under complex stress distribution are now in hand, as also the development of a thermometric and other rapid method of determining fatigue ranges; the effect of high temperatures on the fatigue properties of steels and the determination of the most suitable materials for fundamental research on the structure of metals will shortly be commenced.

In the Chemistry Department investigation on the strength of cotton fabric with rate of loading and effect of humidity on the weight of fabric has been completed. Other investigations now in hand include the testing of the purity of hydrogen, air leakage of balloon fabrics, and studies of the properties of cellulose acetate. A recent report on the study of hygrometric methods which is very comprehensive has been communicated to another Government department.

In the Metallurgy Department the methods of melting and casting aluminium alloys with special reference to current problems

has been continued on the lines commenced under the auspices of the late Light Alloys Sub-Committee. The investigation of casting temperatures, contractions during casting, fatigue and repetition stresses are also in hand, while the constitutional work on thermal equilibrium diagrams for binary and ternary alloys is not being neglected.

The Royal Aircraft Establishment have in hand a mathematical investigation of the stresses due to surface scratches, rate of variation of cross section and internal cracks in materials. They are also making a number of experiments on the effect of alternating torsional over-strain on the density and elastic moduli of steel, the fatigue of riveted joints and on the effect of low temperatures on fatigue resistances.

In the Chemistry Division experiments are being made on dope solvent recovery and new softeners; also mechanical methods such as the application of dope by spraying. Reinforced cotton fabric is being tested, and routine tests with reference to recent demands for airships and aeroplanes is receiving attention.

Light alloy work at this Establishment is being directed to foundry trials of all promising new light alloy compositions; to methods of casting light alloys on to steel; and to the growth of aluminium castings and the method of electro-deposition.

At the various Universities the programme of research relates mainly to work on the fatigue of materials. At Birmingham, Professor Lea will commence an extensive research on the fatigue properties of valve steels at various temperatures, and the correlation of the fatigue properties of materials with their physical and mechanical properties. At Oxford, attention is to be paid to an investigation on the effect of scratches at various depths on the surface of a specimen under fatigue loads. At Liverpool, Professor Mason will experiment on the application of bending and twisting in various proportions to different materials, with measurements of the cyclic strains. Professor Gibson, of Manchester University, will make measurements on the three moduli for various materials. At Edinburgh, Professor Hudson Beare will investigate the fatigue on spiral springs. At Bristol University, Professor A. Robertson will experiment on the stress and strain in steels near the yield point; Professor Desch, at Sheffield, will continue his work on the electro-deposition of cadmium and nickel for the protection of aeronautical structures from corrosion.

Nomenclature.—Definitions and nomenclature for use in the discussion of static design tests have now been embodied in a report of the Elasticity and Fatigue Panel, which report will be circulated to those undertaking researches for the Committee at the various universities, and to other persons concerned. It is not proposed for the present that the report, which includes a list of possible terms, should be published. Nor is it proposed

that any steps should be taken as yet towards standardisation of these terms. The report is, however, expected to prove useful in making for conformity in terms used in reports presented to the Sub-Committee, and experiments may indicate its suitability for more general adoption.

Fatigue of materials.—A report describing some experiments on the fatigue of materials under alternating torsion has been communicated by the N.P.L. From a number of tests on a 0·65 per cent. carbon steel the following conclusions have been drawn :—

(1) That the fatigue limit under reversed shear stresses is marked by a " breakdown " or " yield " point in the material, as in Smith's experiments with direct stresses.

(2) That this breakdown point is independent of the form of the section (solid or hollow).

(3) That Guest's Law applies to fatigue stresses.

The paper, which will shortly be published, is of special interest as the time taken to determine the fatigue limit of one specimen by the new method is only from 3 to 15 minutes. Owing to the fact that the maximum stress occurs only at one section, the breakdown will probably be visible as an elastic limit effect rather than as a yield effect; consequently a quick method is possible for determining the fatigue limit.

A number of notched bar impact tests on steels at low temperatures has been completed at the N.P.L. They show that with mild steel there is a very large reduction in the energy absorbed in breaking a notched test piece when the temperature is reduced to — 38·5°C. and below. This reduction in the energy absorbed is attributed to the presence of notches. With reference to these and similar tests, attention has been drawn to the scale effect obtaining in them, particularly in the case of notched bar impact tests. This has been taken account of by a note on the subject which draws attention to the fact that the time of fracture ranges from one to four-thousandths of a second, so that many more reflections will occur in some cases, during the process of fracture. It seems probable that much of the measured work of fractures will have been propagated through the swinging arm into parts of the apparatus where it will be lost by dissipation, so that there will be a certain " missing quantity " of the experiment which will not necessarily be a constant fraction of the whole, but will depend upon the time of fracture, *i.e.*, upon the striking velocity.

The effect of heat treatment on the value of a modulus (Young's Modulus) has also been ascertained at the N.P.L. The maximum effect due to heat treatment alone was found in the case of the $2\frac{3}{4}$ nickel and 0·25 carbon steel to be 4 per cent. Other experiments show the modulus of rigidity can be readily

obtained to an accuracy of $\pm$ 1 per cent. The tensile stress of steels with high percentage of carbon is another matter that has been investigated, and it is found that those materials have a high tensile stress at high temperatures and that this strength is nearly equalled by high chromium steels also containing a high percentage of carbon. In considering these tests, it becomes evident that a percentage of carbon plays an important part in determining the stress.

The theory of spiral fractures in propeller shafts has been considered from a theoretical standpoint. It has been suggested that no satisfactory explanation has yet been made of this phenomenon. From a consideration of the theoretical distribution of stress round a small spherical flaw in isotropic elastic material, it has been suggested that the directions in which fatigue fractures tend to spread, in material of which the planes of greatest weakness have on the whole no definite orientation, will be roughly perpendicular at any point to the greatest principal tensile stress. On the other hand, it has been suggested that in some substances—*e.g.*, mild steel—fracture tends to follow the planes of maximum shear.

Light alloys.—Two reports on light alloys have been issued. The first gives the results of static tensile tests on duralumin made by Professor Dalby, who compares his results with some German tests on duralumin.

Tests have been made at the N.P.L. on rivet material and riveted joints, which lead to the following general conclusions :— The use of various soft rivets consisting of nearly pure aluminium in structural work does not appear to be necessary since perfectly satisfactory joints can be made using either cold drawn and annealed wire of 3/20 alloy or duralumin wire ; and, since both these materials give very much higher shear stresses than soft aluminium wire, there is every reason in favour of the use of the harder material.

A number of tests have been made on pure nickel, which was considered a possible suitable material with which to carry out experiments on combined stresses. From the load extension diagram of this material it can be seen that the metal begins to yield at about 3·5 tons. It then continues along the plastic curve to a maximum load of 9.75 tons. Whether nickel would prove a better material than steel for the general research proposed is still under consideration.

Humidity.—A comprehensive report on methods of measurement of humidity has been communicated by the N.P.L. In it is discussed the wet and dry thermometer of the ventilated type, and the dew point hygrometer, and a method using a variation of refractive index of a glycerine solution with humidity. Other methods are described for measuring the pressure change by various instruments accompanying the absorption of aqueous vapour.

Strength and weight of aeroplane structure materials.—A paper drawing attention to the general relations established between the strengths required by different materials in order to produce structures of equal weights has been communicated to the Committee, and has since been published. The following results are obtained :—

(1) For the flanges of members subjected to bending, either simple or accompanied by axial loading, 45 ton steel will have the same weight as duralumin.

(2) For strut members the steel used requires a modulus of elasticity of 13,200 tons/sq. in. to reduce the weight to that of equally strong duralumin members.

(3) The flexibility of steel and duralumin beams will be equal if 45 ton steel is used. For higher grades, steel construction is more flexible than duralumin.

From the foregoing it would appear that for small craft, where the thicknesses of steel required would be impossibly small, duralumin gives a lighter construction. For large aeroplanes, however, steel appears undoubtedly the better material.

Fabrics and Dopes.

Work has been carried out on the effect of rate of loading on the apparent strength of cotton fabrics used for airships : the results are similar to those obtained for linen in a previous investigation, and indicate that with very slow loading the strength may be considerably less than is found in contractual testing. These experiments are to be extended so as to include the important case of the application of a load initially insufficient to cause rupture.

Various new esters of cellulose have been prepared with a view to obtaining increased waterproofness and greater constancy of tautness in the doped wings of aeroplanes. It is suggested that if constant tautness can be secured it should be possible to utilise some of the strength of the wing covering in the mechanical design of the wing. The tautness of large panels such as those of airship outer covers has also been the subject of experiment and exposure tests.

Methods of determining the humidity of the air have been examined and modified with a view to their use in the study of the effects of moisture on doped fabric, both during and after doping.

In connection with the specification of dope ingredients, a paper has been presented on the suitability of glycerol as a standard for the viscometry of dope solutions.

The question of reducing the risk of fire which attaches to the crashing of aeroplanes continues to receive attention, and many experiments have been carried out both in the laboratory

and on the large scale, in order to locate the sources of greatest danger, so that improvements may be effected if possible at these points.

Various schemes for covering propeller blades have been tried with a view to improving the behaviour under rainy conditions, and some coverings have been shown to be definitely superior to others.

Accidents.

Accidents Investigation Sub-Committee.—The investigations of the accidents to the Felixstowe "Fury" and the Tarrant Triplane "Tabor," mentioned in last year's report have been continued. Investigations have also been made into the risks of negative looping and—arising out of the accident to F.5 boat seaplane at Felixstowe on April 29th, 1920—the controllability and general handling in the air of large flying boats has been discussed.

A report on the accident to the Felixstowe "Fury" was presented to the Air Ministry early in the year. The Sub-Committee found that the Felixstowe "Fury" left the water in a stalled condition, had insufficient power to bring it into control when in the air, and consequently struck the water at an unsuitable angle. From this resulted the collapse of the hull and the subsequent fatal accident. The nature of the conditions which led to the accident were found to be avoidable by suitable design of hull form. This should be such that when running at or near the getting off speed with the heaviest possible loading the natural trim of the craft shall maintain the wings at a safe flying angle, that is, an angle corresponding to a flying speed at least five knots below stalling speed in order that there will be no risk of premature flight. The rate of increase of the water moment with increase in angle beyond that of natural trim should be rapid so that a stalling angle is difficult to attain, while at the same time the power of the controls should permit the pilot to maintain the actual running angle at some 3° more or less than that corresponding to the natural trim. In this way with a heavy sea the pilot will have the option of flying off or preventing premature flight.

It is a characteristic of most boat seaplane hulls that when they make a certain negative angle with the water they dive. This angle in the case of the "Fury" was — 2° : it is important that it should have as large a negative value as possible. In large boats water-tight sub-division of the hull is desirable, and in smaller ones high water-tight dwarf bulkheads are required to prevent the fore and aft movement of free water.

The collating of evidence of the accident to the Tarrant "Tabor" has presented many difficulties in view of the time elapsed, and is still proceeding. The Sub-Committee hope, however, to be in a position shortly to present a report. It is

not thought that any apprehension need be entertained as to the utility of model tests for forecasting the behaviour of even such large aeroplanes.

Enquiry into the question of outside or negative looping showed that this is a manœuvre which may be attended with danger of the machine breaking under the large reversed load which comes upon the wings. There is a certain military value in the manœuvre, but it should therefore be carried out on a machine specially designed to withstand the stresses thus imposed, or whose strength has been investigated and found to be sufficient, and not otherwise. Further, if the manœuvre is to be practised, the design of safety belt for pilot and arrangement of the engine must be established. It was found that some aeroplanes are liable under certain circumstances—and without any intention on the part of the pilot—to go into the initial stages of a negative loop. This only occurs if they are unstable longitudinally.

The accident to F. 5 boat seaplane was due to the pilot making a steeply banked turn with an insufficient margin of flying speed, losing control and going into a spin, and not having sufficient height in which to regain control. The boat struck the water during the process of flattening out after the spin had been checked. The method by which the rudder was balanced was not good, but was not the cause of the accident.

The evidence given by pilots in the course of this enquiry showed, however, that the handling in the air of large flying boats, particularly those of F type, had given considerable trouble, and it appeared that there was little doubt that the trouble with the F boats was mainly due to weathercock instability. Further, it appeared that few data have yet been collected on the lateral stability and control of any type of aircraft. The subject is of such frequent recurrence, in relation to accidents, as to warrant an extended enquiry into the present state of knowledge regarding lateral control and stability : a recommendation to this effect has been put forward, and the matter is being prosecuted.

It was found during this and other enquiries that there are no uniformly accepted meanings attributed to the various terms used in relation to stability or instability of motion, and that the meanings ascribed by pilots to certain of these terms are sometimes at variance with the mathematical conceptions. It was thought to be very desirable to have a scheme of definitions which, while fitting in as far as possible with the definitions used in mathematics and in other sciences, would also be generally accepted by flyers. This would add to the value of reports on the flying qualities of craft, facilitate inquiries into the causes of accidents and conduce to the spread of technical knowledge. Definitions of stability terms are therefore being considered with the above object in view, and it is hoped to publish a report giving such definitions.

Printed under the authority of His Majesty's Stationery Office,
By Sir Joseph Causton & Sons, Limited, 9, Eastcheap, London, E.C.3.